

# New Ramped-Square Sustain Waveform for Improving Luminance and Luminous Efficiency of an AC Surface-Discharge Plasma Display Panel

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**SUMMARY** A new ramped-square sustain waveform is proposed to improve both the luminance and the luminous efficiency of an alternate current plasma display panel (ac PDP). The luminous characteristics such as the luminance and luminous efficiency have been measured with a square-voltage and a ramp-voltage (or voltage slope) of the proposed sustain pulse. With an increase in the square-voltage of a ramped-square sustain waveform, the luminance increases but the luminous efficiency decreases. On the other hand, with an increase in the ramp-voltage of a ramped-square sustain waveform, both the luminance and the luminous efficiency increase. When compared with the conventional square sustain waveform, an improved luminance of 22% and luminous efficiency of 36% are simultaneously obtained based on the proper adjustment of the square-voltage and ramp-voltage of the ramped-square sustain waveform in a 4-inch ac PDP test panel at a frequency of 62 kHz.

**key words:** PDPs, ramped-square pulse, luminous efficiency

## 1. Introduction

Recently, an ac PDP has become one of the most promising candidates for large area (>40-inch) full color wall hanging digital High Definition Televisions (HDTVs). However, for the successful realization of commercial full color digital HDTVs, there have been many problems to be solved, one of which is related with the luminous efficiency including the luminance [1]–[3]. It is well known that as the luminance tends to be saturated with an increase in the discharge current, the corresponding luminous efficiency decreases. Accordingly, the suggestion of an efficient method to lower the discharge current without sacrificing the luminance would contribute to the improvement of the luminous efficiency. In this sense, there have been some previous researches for improving the luminous efficiency using a sustain pulse waveform [4], [5]. The key idea of the previous researches was to enhance the luminous efficiency by producing a self-erasing discharge during a sustain-period in a high frequency region above 160 kHz, how-

ever, so far luminous efficiencies have not been improved without reducing the luminance. Therefore, it is necessary to develop a new sustain pulse waveform for improving the luminous efficiency without reducing the luminance. We have recently reported on the physical concept of the new sustain pulse waveform for improving the luminous efficiency [6]. The proposed sustain pulse waveform was a ramped-square sustain pulse, which was similar to that in this work. However, the previous work has focused only on the improvement of luminous efficiency, and not on the improvement of luminance. Accordingly, in that work, we have not achieved the higher luminous efficiency without reducing the luminance. The luminance decreased to 22%, and also misfiring problem was occurred, even though the higher luminous efficiency of 65% was obtained at the high sustain voltage of 250 V. These side effects such as the reduction of the luminance and the misfiring problem are thought to be due to the too strong self-erasing discharge caused by the high sustain voltage.

This paper presents a new ramped-square sustain waveform with a low square- and ramp-voltage for improving both the luminance and the luminous efficiency. The effects of the square-voltage and ramp-voltage (voltage slope) in the ramped-square sustain waveform on the main and self-erasing discharges in a 4-inch ac PDP test panel at a frequency of 62 kHz are then examined.

## 2. Experiment

Figure 1 shows the experimental setup for the measurement employed in this research. The PR-704 spectrometer was used to measure the luminance of 4-inch ac PDP test panel. Table 1 shows the panel design specifications of the 4-inch ac PDP test panel utilized in this experiment. The power consumption dissipated in the 4-inch PDP test panel was measured in the input line between the driving circuits and the test panel using the PM3000A power analyzer. The voltage and current waveforms were measured by the voltage and current probes, respectively. The infrared (IR: 828 nm) signals were measured by the digital oscilloscope after being converted into electrical signals by the PMT tube. In

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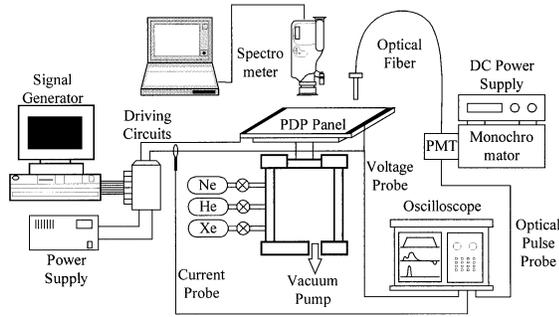


Fig. 1 Experimental setup for measurements.

Table 1 Panel design specifications of 4-inch ac PDP test panel employed in this experiment.

ITO Width	310 $\mu\text{m}$
ITO Gap	80 $\mu\text{m}$
Bus Electrode Width	100 $\mu\text{m}$
Address Electrode Width	100 $\mu\text{m}$
Barrier Rib Width	70 $\mu\text{m}$
Barrier Rib Height	150 $\mu\text{m}$
Cell Pitch	360 $\mu\text{m}$
Gas Composition	Ne (96%) + Xe (4%)
Gas Pressure	400 Torr

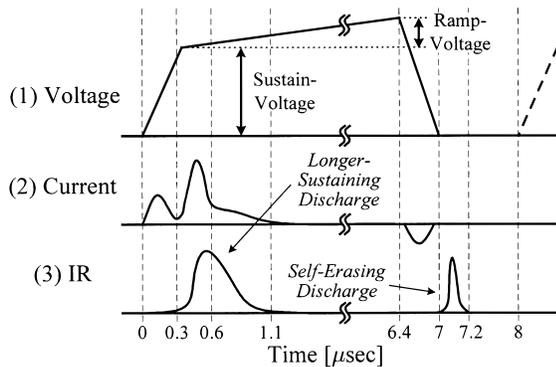


Fig. 2 Voltage (1), current (2) and IR (3) waveform with ramped-square sustain pulse.

this experiment, the Address-Display-Separated (ADS) driving scheme was used to drive the 4-inch PDP test panel, and the sustain pulse shape in a sustain period was only modified from the square pulse shape into the ramped-square shape.

### 3. Discharge Characteristics of Ramped-Square Sustain Waveform

Figure 2 shows the schematic waveforms of the voltage (1), current (2) and infrared (IR: 828 nm) (3) based on the actual waveforms measured from the 4-inch ac

PDP test panel with the ramped-square sustain waveform [7]. The ramped-square sustain waveform is a superimposed waveform, which adds a ramp-waveform to a conventional square sustain waveform with a same pulse width, and has a constantly increasing voltage slope between the rising and falling edge of the sustain pulse, as shown in Fig. 2(1). The voltage of square-waveform in the ramped-square waveform, namely the voltage at the rising edge of the ramped-square sustain pulse (hereafter, this will be called 'square-voltage'), has conditions of 150, 160, 170 and 180 V. The value of voltage difference between the rising and falling edge of the ramped-square sustain pulse (hereafter, this will be called 'ramp-voltage'), has the conditions of 0, 10, 20, 30 and 40 V, indicating that the increasing voltage slopes are 0, 1.5, 3.1, 4.6, and 6.2 V/ $\mu\text{sec}$ , respectively. The other driving conditions are a frequency of 62 kHz, duty ratio of 40%, rising time of 300 nsec, and falling time of 600 nsec.

When the wall charges are accumulated on two sustain electrodes via an address period, the displacement current starts to flow with the applied sustain pulse. Then, the electric field generated between two sustain electrodes by the applied voltage plus wall voltage, produces the main discharge, and the discharge current begins to flow at 0.3  $\mu\text{sec}$ , as shown in Fig. 2(2). The IR is then simultaneously emitted. An increase in the IR intensity means that the VUV emission produced in the PDP cell increases. In the case of a conventional square sustain pulse, the plasma discharge is extinguished immediately because of the accumulation of wall charges with opposite polarity to applied voltage. Hence, the discharge current and IR intensity also decrease rapidly. The energetic space charges and metastable atoms still remain within the cell after the extinction of the main discharge. In the case of a ramped-square sustain pulse, however, the constantly increasing voltage slope prevents the rapid reduction of an electric field caused by the accumulation of wall charges. Therefore, this new sustain waveform can prevent an immediate extinction of plasma discharge, resulting in inducing a longer sustaining discharge. More energetic space charges and metastable atoms can be utilized in the case of a longer sustaining discharge, thereby contributing to the improvement of a luminous efficiency. However, it is important to note that all the ramped-square sustain waveforms cannot induce a longer sustaining discharge. To compensate the electric field intensity reduced due to the wall voltage, the increasing voltage slope in the ramped-square sustain waveform needs to be greater than the wall voltage with opposite polarity to applied sustain pulse. Thus only the ramped-square sustain waveforms with the ramp-voltage greater than the wall voltage produced by the accumulation of the wall charges can induce a longer sustaining discharge. In other words, a longer sustaining discharge depends on the magnitude of the ramp-

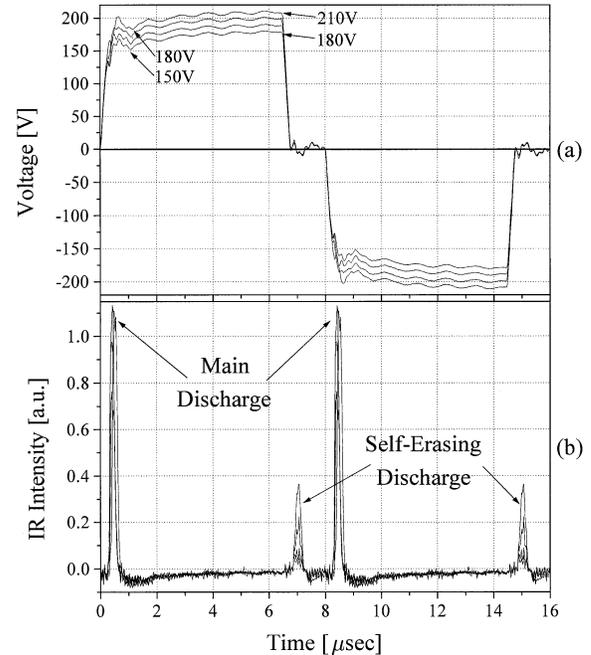
voltage, namely increasing voltage slope. The ramp-voltages for inducing a longer sustaining discharge vary according to the wall voltages, which are determined by the amount of accumulation of wall charges. In this experiment, the ramped-square sustain waveforms with the ramp-voltages greater than 20 V began to produce a longer sustaining discharge.

After the longer sustaining discharge, the electric field intensity kept constant due to the constantly increasing voltage slope, transforming the space charges into the additional wall charges. This excessively accumulated wall charges can produce a self-erasing discharge at the falling edge of the ramped-square sustain pulse, as shown in Fig. 2(3). As the self-erasing discharge is produced only by the wall charges, it requires no additional power consumption, thereby improving the luminous efficiency. Although considerable amount of the wall charges is removed due to the self-erasing discharge, the space charges are still produced after the self-erasing discharge. These space charges can play the same role as the priming particles in the dc PDP. If the next sustain pulse is applied before the disappearance of space charges, the next main discharge can be produced using the space charges instead of the wall charges. However, it is very difficult to separate whether the main contribution factor for improving the luminance and luminous efficiency is a longer sustaining discharge at the rising edge or a self-erasing discharge at the falling edge in this ramped-square sustain waveform. In addition, it is quite difficult to separate whether the longer sustaining discharge is due to the increasing voltage slope or the previous self-erasing discharge caused by the increasing voltage slope. We will try to make these two point clear through the further study on the discharge physics of the ramped-square sustain waveform. The detailed physical description of the ramped-square sustain waveform was discussed in our previous work [7].

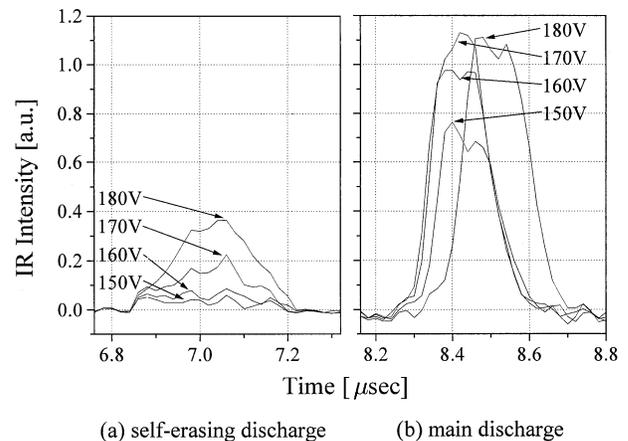
## 4. Results and Discussion

### 4.1 Effects of Square-Voltage in Ramped-Square Sustain Waveform

Figure 3 shows the changes in the voltage (a) and IR (b) waveforms measured from the 4-inch ac PDP test panel as a variation of square-voltage of the new ramped-square sustain pulses at a constant ramp-voltage of 30 V. The square-voltage conditions are 150, 160, 170 and 180 V, and the voltage slope is about 4.6 V/ $\mu$ sec in all square-voltages. The horizontal axes of Figs. 3(a) and (b) are the same time scale. As shown in Figs. 3(a) and (b), the main discharge and the self-erasing discharge are produced at the rising and falling edge of the proposed pulse, respectively, indicating that the ramped-square sustain waveform can induce two light pulses per one sustain pulse. Figure 4(a) shows the

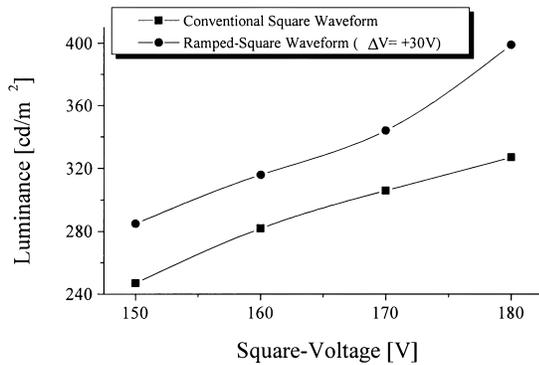


**Fig. 3** Changes in IR intensity (b) of main discharge at the rising edge and self-erasing discharge at the falling edge with various square-voltages of the ramped-square sustain waveforms (a).



**Fig. 4** Changes in the intensities of IR waveforms produced from the self-erasing discharge (a) and the next main discharge (b) with various square-voltages of the ramped-square sustain waveforms.

changes in the IR intensity emitted from the self-erasing discharge during 6.8–7.3  $\mu$ sec at the falling edge with an increase in the square-voltage of a ramped-square sustain pulse. As shown in Fig. 4(a), the self-erasing discharge intensity becomes strong as the square-voltage increases. This strong self-erasing discharge is due to the larger amount of wall charges accumulated in the main discharge. Since the main discharge intensity before a self-erasing discharge becomes strong in proportion to the increase in the square-voltage, more space charges, which are converted into the wall charges, are

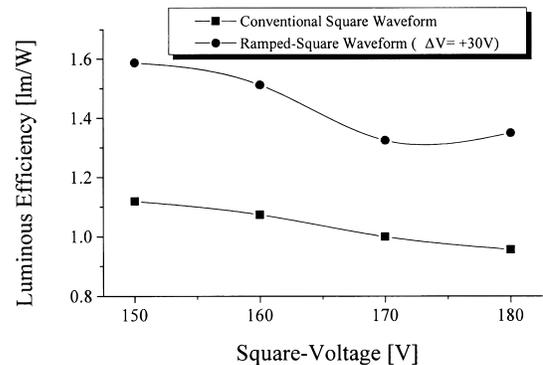


**Fig. 5** Changes in luminance of conventional square waveform and new ramped-square waveform with a constant ramp-voltage of 30 V as a variation of square-voltage.

generated in the cell. Therefore, as the square-voltage of a ramped-square sustain pulse increases, the self-erasing discharge intensity becomes stronger, as shown in Fig. 4(a).

Figure 4(b) shows the changes in the IR intensity emitted from the main discharge during 8.2–8.8  $\mu\text{sec}$  at the rising edge after the self-erasing discharge with an increase in the square-voltage of a ramped-square sustain pulse. The vertical axes of Figs. 4(a) and (b) are the same scale. As shown in Fig. 4(b), the main discharge is produced more strongly with higher square-voltage, except for the square-voltage condition of 180 V. In a conventional self-erasing sustain discharge, if the sustain pulses applied have the same amplitudes, the IR intensity emitted from the main discharge tends to decrease as the self-erasing discharge intensity increases [6]. In this experiment, however, the IR intensity from the main discharge does not decrease even though the self-erasing discharge intensity increases with an increase in the square-voltage of a ramped-square sustain pulse. In addition, at the square-voltage of 180 V, the intensity of the self-erasing discharge prior to the main discharge is produced so strongly, compared with that of the self-erasing discharge at the square-voltage of 170 V, that the emission of the IR from the main discharge is delayed and sustained slightly longer, as shown in Fig. 4(b). This phenomenon is presumably due to the changes in the conversion rate of the wall charges into the space charges according to the intensity of the self-erasing discharge. We will make this point clear through the further study.

Figures 5 and 6 show the changes in the luminance and luminous efficiency with an increase in the square-voltages from 150 V to 180 V, in the cases of a ramped-square sustain waveform with a constant ramp-voltage of 30 V and a conventional square sustain waveform, respectively. As shown in Fig. 5, the luminance of a ramped-square sustain waveform at all square-voltage conditions is improved above 15%, compared with that of a conventional square sustain waveform. As the lu-



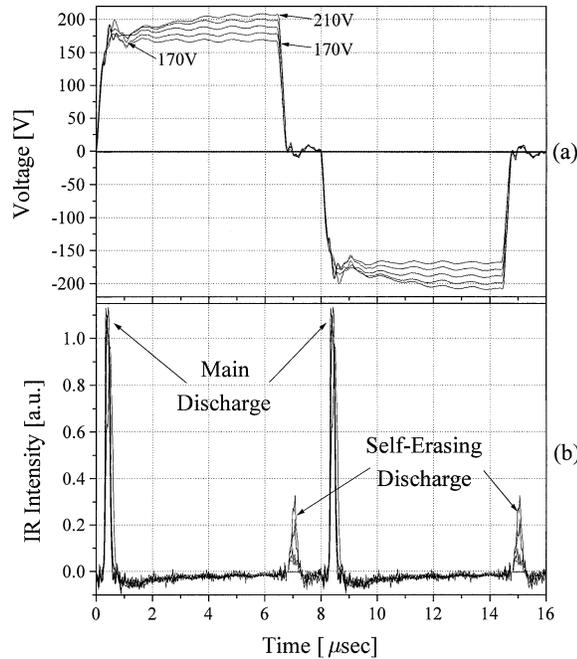
**Fig. 6** Changes in luminous efficiency of conventional square waveform and new ramped-square waveform with a constant ramp-voltage of 30 V as a variation of square-voltage.

minance is proportioned to the light intensity emitted from the main discharge plus the self-erasing discharge, the luminance of the ramped-square sustain waveform increases with an increase of the square-voltage. As shown in Fig. 6, the luminous efficiency of the ramped-square sustain waveform at all square-voltage conditions is also improved above 30%, compared with that of a conventional square sustain waveform. The reason is that the ramped-square sustain waveform can induce two light pulses per one sustain pulse irrespective of the amplitude of the square-voltage.

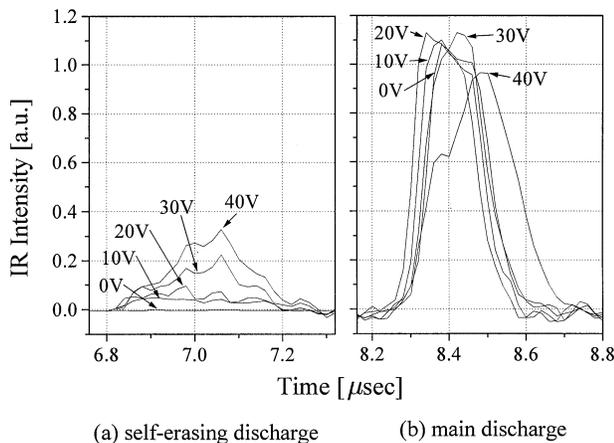
#### 4.2 Effects of Ramp-Voltage in Ramped-Square Sustain Waveform

Figure 7 shows the changes in the voltage (a) and IR (b) waveforms measured from the 4-inch ac PDP test panel as a variation of the ramp-voltage of a new ramped-square sustain pulse at a constant square-voltage of 170 V. The ramp-voltage conditions are 0, 10, 20, 30 and 40 V, indicating that the voltage slopes are 0, 1.5, 3.1, 4.6 and 6.2  $\text{V}/\mu\text{sec}$ , respectively. The horizontal axes of Figs. 7(a) and (b) are the same time scale. Figure 8(a) shows the changes in the IR intensity emitted from the self-erasing discharge during 6.8–7.3  $\mu\text{sec}$  at the falling edge with an increase in the ramp-voltage of a ramped-square sustain pulse. As shown in Fig. 8(a), the self-erasing discharge is produced at the ramp-voltage greater than 0 V, and the self-erasing discharge intensity becomes strong as the ramp-voltage increases. The increase in the ramp-voltage of a ramped-square sustain waveform means that the electric field intensity in the discharge cell after the discharge-off at the rising edge becomes stronger in proportion to the increasing ramp-voltage slope. The electric field is so strong that additional wall charges can be accumulated from the space charges. This then causes a strong self-erasing discharge due to the excessively accumulated wall charges at the falling edge of a ramped-square sustain pulse.

Figure 8(b) shows the changes in the IR intensity

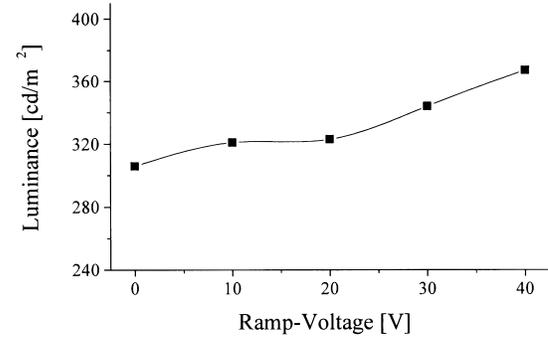


**Fig. 7** Changes in IR intensity (b) of main discharge at the rising edge and self-erasing discharge at the fall edge with various ramp-voltages of the ramped-square sustain waveform (a).

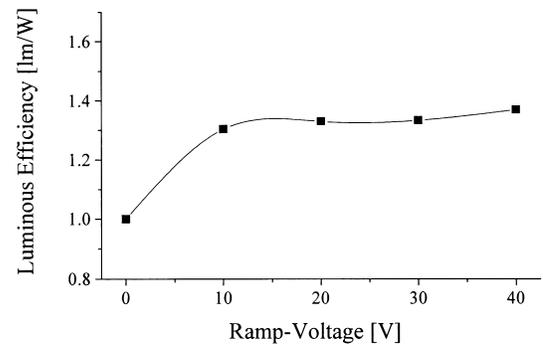


**Fig. 8** Changes in the intensities of IR waveforms produced from the self-erasing discharge (a) and the next main discharge (b) with various ramp-voltages of the ramped-square sustain waveforms.

emitted from the main discharge during 8.2–8.8  $\mu\text{sec}$  at the rising edge after the self-erasing discharge with an increase in the ramp-voltage of a ramped-square sustain pulse. The vertical axes of Figs. 8(a) and (b) are also the same scale. As shown in Fig. 8(b), in the case of the increased ramp-voltage of a ramped-square sustain waveform, the IR intensity emitted from the main discharge rarely changes except for the ramp-voltage of 40 V, even though the self-erasing discharge prior to the main discharge becomes strong. The pulse widths of IR waveforms measured at the half point of peak value



**Fig. 9** Changes in luminance of the conventional square sustain waveform (ramp-voltage=0 V) and the new ramped-square sustain waveforms (ramp-voltage > 0 V) with a constant square voltage of 170 V as a variation of ramp-voltage.



**Fig. 10** Changes in luminous efficiency of the conventional square sustain waveform (ramp-voltage=0 V) and the new ramped-square sustain waveforms (ramp-voltage>0 V) with a constant square voltage of 170 V as a variation of ramp-voltage.

range from 229 to 231 nsec as the ramp voltages increase from 0 to 20 V at the constant square voltage of 170 V. At the ramp-voltage of 30 V, the IR pulse width is approximately 240 nsec, indicating that this magnitude of the ramp-voltage begins to induce a longer sustaining discharge. In particular, at the ramp-voltage of 40 V, the IR pulse width is approximately 320 nsec, indicating that the main discharge at the rising edge remains during much longer time. As a result, the longer sustaining main discharge at the rising edge can be induced if the ramped-square sustain waveform has the high ramp-voltage slope of 6.2 V/ $\mu\text{sec}$ . However, the self-erasing discharge intensity at the ramp-voltage of 40 V is so strong that the IR intensity emitted from the main discharge is slightly reduced, as shown in Fig. 8(b).

Figures 9 and 10 show the changes in luminance and luminous efficiency with increased ramp-voltages from 0 V to 40 V in the case of a ramped-square sustain waveform at a constant square-voltage of 170 V. Since the luminance is determined based on the light emitted from a self-erasing discharge plus a main discharge, the luminance of the ramped-square sustain pulse is brighter than that of the conventional square sustain pulse, as shown in Fig. 9. The improvement rate

of a luminance shows a maximum value of 20% when the strongest self-erasing discharge is produced at 40 V ramp-voltage condition. As shown in Fig. 10, the luminous efficiency of the ramped-square sustain pulse is improved more than 30%, compared with that of the conventional square sustain pulse. The improvement rate of a luminous efficiency shows a maximum value of 37% when the strongest self-erasing discharge is produced at 40 V ramp-voltage condition. This improvement is due to both the longer-sustaining main discharge at the rising edge and the strong self-erasing discharge at the falling edge in the ramped-square sustain waveform with a high ramp-voltage slope of 6.2 V/ $\mu$ sec.

## 5. Conclusion

A new ramped-square sustain waveform is proposed to improve both the luminance and the luminous efficiency of an alternate current plasma display panel (ac PDP). The luminous characteristics such as the luminance and luminous efficiency have been measured with a square-voltage and a ramp-voltage (or voltage slope) of the proposed sustain pulse. It is found that the luminance and luminous efficiency strongly depend on the discharge characteristic relation between the main discharge at the rising edge and the self-erasing discharge at the falling edge of the ramped-square sustain waveform. When compared with the conventional square sustain waveform, an improved luminance of 22% and luminous efficiency of 36% are simultaneously obtained based on the proper adjustment of the square-voltage and ramp-voltage of the ramped-square sustain waveform in a 4-inch ac PDP test panel at a frequency of 62 kHz.

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