Study on the Second-Order Sustaining Driver for Plasma Display Panel

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Abstract

The sustaining driver for plasma display panel (PDP) should provide alternating high voltage pulses to ignite plasma and recover the energy stored in the intrinsic capacitance between the scanning and sustaining electrodes inside the panel. Second-order circuits utilizing the series-connected or parallel-connected external inductance and intrinsic capacitance have been successfully adopted for the sustaining driver. In this way, high efficiency and low component count can be achieved. In this paper, the electrical characteristics of second-order drivers in the sustaining operation mode are investigated and influence of the ignited plasma discharging current on the driver performance is discussed.

I. Introduction

Plasma display panels which have the large view angle and potentially large screen dimensions take advantages over the other competing flat panel technologies and are expected to be the displays of the next generation. PDPs comprise a structure including a pair of substrates respectively supporting scanning, sustaining and addressing electrodes each coated with a dielectric layer. A desired color light display function is achieved by exciting those phosphors on the dielectric layer to emit visible light with the ultraviolet photons generated by the gas discharge.

PDPs are arrays of individually controllable electric discharges in short gaps [1] and its fundamental driving operations are addressing and sustaining. In the addressing period, selective-write discharges can be initiated at given discharge cells by applying data pulses to the addressing electrodes and scanning pulses to the scanning electrodes at the same timings. Afterwards, the discharges at the selected cells can be continuously "sustained" between sustaining electrodes and adjacent scanning electrodes by applying alternating voltage pulses which themselves are insufficient to initiate a discharge. The intrinsic panel inter-electrode capacitance is formed because a dielectric layer exists between scanning and sustaining electrodes and there is unacceptably high power dissipation for large diagonal panels in the plasma display sustaining driver. With the view of high efficiency, not only should provide alternating voltage pulses to ignite plasma, the sustaining driver but also recovers the energy stored in the intrinsic panel capacitance.

In Section II, two types of second-order sustaining drivers that utilize effects of series-resonance and parallel-resonance respectively are discussed. As a result of the electric breakdown of

the gas mixture when charging the intrinsic panel capacitance, the subsequent transient electric discharges causes an ignited plasma discharging current. In Section III, a mathematical attempt is made to analyze the influence of the discharging current on the two types of second-order sustaining drivers.

II. Series-Resonance and Parallel-Resonance Sustaining Drivers

To provide alternating sustaining voltage across the intrinsic panel capacitance, the plasma display sustaining driver generally includes a charging and discharging circuit and a voltage clamping circuit. The intrinsic panel capacitance is dependent on the panel size. Among different kinds of sustaining drivers, a voltage clamping circuit that adopts the full bridge configuration is usually utilized. The panel electrodes are connected between the two legs of the full bridge circuit. The intrinsic panel capacitance is then charged and discharged through an inductor instead of through the lossy resistance of switches [2]. Two typical second-order sustaining drivers are respectively shown in Fig.1 and Fig.2.

A. Series-Resonance Sustaining Driver [3]

The sustaining driver in Fig.1 comprises two independent charging and discharging circuits. One is on the scanning side and the other is on the sustaining side. Considering only the scanning side circuit, the intrinsic panel capacitance C_p and the energy recovery capacitance C_s are series connected by an external inductor L and the sustaining driver utilizes the series resonance among C_p , L , and C_s to charge or discharge the intrinsic panel capacitance. In other words, the energy discharged from the energy recovery capacitance C_s is used to charge the intrinsic panel capacitance C_p and the energy discharged

from the intrinsic panel capacitance C_p can also be temporarily stored in the energy recovery capacitance C_s . Therefore, most energy is recovered and high efficiency is achieved.

We assume the voltage across the intrinsic panel capacitance C_p initially is zero and the voltage of the energy recovery capacitance C_s has reached the steady state, one half of the sustain voltage V_s . When the intrinsic panel capacitance C_p is charged, the voltage across the panel can be expressed as

$$V_{C_p}(t) = -\frac{V_s}{2} \frac{C_s}{C_p + C_s} \cos\left(\sqrt{\frac{C_p + C_s}{LC_p C_s}} t\right) + \frac{V_s}{2} \frac{C_s}{C_p + C_s}. \quad (1)$$

From the equation (1), the intrinsic panel capacitance C_p can be charged to the voltage $V_s \frac{C_s}{C_p + C_s}$ during one half of the resonance period with the help of the bi-directional switch that is made up of M5, M6, D1, and D2. Note that for high power efficiency, the energy recovery capacitance C_s must be much larger than the intrinsic panel capacitance C_p . However, it takes considerable time until the steady state is reached. To solving this problem, an additional start-up circuit is necessary to charge the large energy recovery capacitance C_s .

B. Parallel-Resonance Sustaining Driver [4]

The parallel resonance between the intrinsic panel capacitance C_p and the external inductor L in Fig.2 is the other energy recovery method. If the voltage across the intrinsic panel capacitance C_p initially is $-V_s$ and the inductor current L is zero, then

$$V_{C_p}(t) = -V_s \cos\left(\frac{1}{\sqrt{LC_p}} t\right). \quad (2)$$

The equation (2) means that during one half of the resonance period the intrinsic panel capacitance C_p can be charged again to the opposite polarity by a resonant current generated when the intrinsic panel capacitance C_p is discharged. The energy in

discharging the intrinsic panel capacitance C_p is transferred temporarily to the inductor L and subsequently again transferred from the inductor L to the intrinsic panel capacitance C_p .

Fig.1 Series-resonance sustaining driver

Fig.2 Parallel-resonance sustaining driver

III. Influences of the Discharging Current on the Sustaining Drivers

Due to the generation of the ignited plasma discharging current when charging the intrinsic panel capacitance to exceed the firing voltage V_f , something different affects the performance of the sustaining drivers. In order to evaluate the influence of the discharging current and avoid the degradation of the sustaining drivers, we should model the panel as a capacitance, parallel connected with a current source $i_d(t)$. $i_d(t)$ can be expressed as

$$i_d(t) = \begin{cases} 0, & t = 0 \sim t_1 \\ I_D, & t = t_1 \sim t_2 \\ 0, & t = t_2 \sim \frac{T}{2} \end{cases}, \quad (3)$$

where the voltage of the intrinsic panel

capacitance at $t = t_1$ is equal to the firing voltage V_f and at the same time the discharging current I_D is generated and maintained until $t = t_2$. T represents the resonance period. The simplified charging and discharging circuit of the series-resonance sustaining driver is illustrated in Fig.3. According to the initial conditions such as $V_{C_p}(t=0) = 0$, $i_L(t=0) = 0$, and $V_{C_S}(t=0) = \frac{V_S}{2}$, the

following equation (4) can be derived and the voltage waveform across the intrinsic panel capacitance is drawn in Fig.4.

$$V_{C_p}(t) = \begin{cases} -\frac{V_S}{2} \frac{C_S}{C_p + C_S} \cos\left[\sqrt{\frac{C_p + C_S}{LC_p C_S}} t\right] + \frac{V_S}{2} \frac{C_S}{C_p + C_S}, & t = 0 \sim t_1, \\ \frac{i_L(t_1) - \frac{C_S}{C_p + C_S} I_D}{C_p \sqrt{\frac{C_p + C_S}{LC_p C_S}}} \sin\left[\sqrt{\frac{C_p + C_S}{LC_p C_S}} (t - t_1)\right] \\ + \frac{[V_f - V_{C_S}(t_1)] C_S}{C_p + C_S} \cos\left[\sqrt{\frac{C_p + C_S}{LC_p C_S}} (t - t_1)\right] \\ - \frac{I_D}{C_p + C_S} (t - t_1) + \frac{C_p V_f + C_S V_{C_S}(t_1)}{C_p + C_S}, & t = t_1 \sim t_2, \\ \frac{i_L(t_2) - \frac{C_S}{C_p + C_S} I_D}{C_p \sqrt{\frac{C_p + C_S}{LC_p C_S}}} \sin\left[\sqrt{\frac{C_p + C_S}{LC_p C_S}} (t - t_2)\right] \\ + \frac{[V_{C_p}(t_2) - V_{C_S}(t_2)] C_S}{C_p + C_S} \cos\left[\sqrt{\frac{C_p + C_S}{LC_p C_S}} (t - t_2)\right] \\ + \frac{C_p V_{C_p}(t_2) + C_S V_{C_S}(t_2)}{C_p + C_S}, & t = t_2 \sim \frac{T}{2}. \end{cases} \quad (4)$$

Fig.3 The simplified charging and discharging circuit of the series-resonance sustaining driver
($C_p = 20nF$, $C_S = 660\mu F$, $L = 5\mu H$)

Fig.4 Influence of the discharging current on the series-resonance sustaining driver

$$(V_S = 200V, V_f = 150V, I_D = 20A, t_2 - t_1 = 100ns)$$

Fig.5 is the simplified charging and discharging circuit of the parallel-resonance sustaining driver. According to the initial conditions such as $V_{C_p}(t=0) = -V_S$ and $i_L(t=0) = 0$, the following equation (5) can be derived and the voltage waveform across the intrinsic panel capacitance is drawn in Fig.6.

$$V_{C_p}(t) = \begin{cases} -V_S \cos\left[\frac{1}{\sqrt{LC_p}} t\right], & t = 0 \sim t_1, \\ -\frac{i_L(t_1) - I_D}{\sqrt{\frac{C_p}{L}}} \sin\left[\frac{1}{\sqrt{LC_p}} (t - t_1)\right] \\ + V_f \cos\left[\frac{1}{\sqrt{LC_p}} (t - t_1)\right], & t = t_1 \sim t_2, \\ -\frac{i_L(t_2)}{\sqrt{\frac{C_p}{L}}} \sin\left[\frac{1}{\sqrt{LC_p}} (t - t_2)\right] \\ + V_{C_p}(t_2) \cos\left[\frac{1}{\sqrt{LC_p}} (t - t_2)\right], & t = t_2 \sim \frac{T}{2}. \end{cases} \quad (5)$$

Fig.5 The simplified charging and discharging circuit of the parallel-resonance sustaining driver ($C_p = 20nF$, $L = 5\mu H$)

Fig.6 Influence of the discharging current on the parallel-resonance sustaining driver

$$(V_S = 200V, V_f = 150V, I_D = 20A, t_2 - t_1 = 100ns)$$

Fig.7 is the experimental voltage waveform between the scanning and sustaining electrodes and the influence of the discharging current on the sustaining drivers is shown in the dashed-circle. From Fig.4, Fig.6 and Fig.7, the designed resonance condition is destroyed because the discharging current would dissipate some of the energy used to charge the intrinsic panel capacitance. Therefore, while the discharging current appears, the voltage across the intrinsic panel capacitance may decline sharply and the best power efficiency cannot be achieved by means of the previous switching time of the bi-directional switch. Furthermore, we find that using a smaller inductor is able to improve the decline of the voltage across the intrinsic panel capacitance somewhat but the inductor current becomes larger. Besides, from Fig.4 and Fig.6, the intrinsic panel capacitance could be charged to a higher voltage by the series-resonance charging circuit than by the parallel-resonance charging circuit. The reason is that the energy stored in the energy recovery capacitance can be served to generate the discharging current.

Fig.7 The experimental voltage waveform between the scanning and sustaining electrodes

IV. Conclusion

According to the analysis in Section II, we find that the parallel-resonance sustaining driver does not need the energy recovery capacitance C_S in comparison with the series-resonance sustaining driver but the energy recovery function is also achieved. In addition, the discharging current would affect the performance of the two sustaining drivers. To reduce the influence on the sustaining drivers and still keep the best power efficiency, we should use a smaller inductor or adjust the switching time of the bi-directional switch.

V. References

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