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# High Efficient AC-PDP Energy Recovery Circuit Employing Step-Up Faculty

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# 승압 기능을 가지는 AC-PDP 구동을 위한 고효율 에너지 회수 회로에 대한 연구

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## ABSTRACT

**The sustain driver for AC plasma display panel should provide alternating high voltage pulses to ignite plasma and recover the energy discharged from the intrinsic capacitance between the scanning and sustaining electrodes inside the panel. In this paper, an efficient sustain circuit employing boost-up function is proposed to achieve a faster rise-time in order to be suitable to widely used the address display period separated (ADS) driving method. The proposed circuit improves the recovery efficiency, regardless of the variation of the panel capacitance. The principle of operation, features, and simulated results are illustrated and verified on a 7.5-inch diagonal panel at 200 [kHz] operating frequency based on experimental prototype.**

***Index Terms - Plasma display panel (PDP), sustain driver, address-display-separated (ADS) method***

## I. INTRODUCTION

In recent, AC plasma display panel (PDP) has been given a promise to be an attractive solution for high definition television (HDTV) and large flat TV displays. But high power loss and high cost are still the major concerned issues. The sustain driver for AC-PDP equipped with an energy recovery function that can considerably improve the overall system efficiency is the most recent design trend [1]-[15].

In addition, to be suitable for widely used ADS (Address Display period Separated) driving method, there is a limitation to the voltage rise time. To increase scan lines and sub-fields to reduce false contour, there happens defects that cannot obtain sufficient brightness due to the reduction of sustain period. To solve this brightness decreasing problem, a method increasing the number of sustain pulses by decreasing sustain pulse period is often used [5]. However, if the width of sustain pulses is limited due to sustain voltage rise time, operation margin tends to be reduced [6]-[8]. In this case, rise-time is limited by sustain pulse width, if when the conventional energy recovery circuit that depends only upon a resonance between the panel capacitance and an external inductor is equipped with the panel, the energy recovery efficiency will be reduced due to incomplete resonance. This problem can be alleviated by a faster resonant time via reducing inductor value. But the solution is not suitable for the resonant type energy recovery circuit, because the larger inductor value guarantees the higher energy recovery efficiency.

Fig. 1 shows a simplified equivalent structure of AC-PDP. In this figure, $C_s$ is the capacitance of glass substrates, and $C_d$ is the capacitance due to a dielectric layer between electrodes. And $C_d^*$ means the capacitance between the dielectric layer on the electrode and igniting space. $C_g$ means the capacitance due to the gas in discharge space. Because the address electrodes are only used during the writing or erasing operation, and are normally connected to ground during sustain periods, a capacitor $C_p$ can be replaced by the equivalent circuit of the PDP. Therefore, total panel capacitance can be expressed as:

$$C_p = C_d^* \| C_g \| C_d^* + C_d + C_s \approx C_g + C_s \tag{1}$$

During the discharging period, the characteristic of gas in discharging space is changed from insulated to conductive. As a result, capacitance $C_g$ is dynamically changed forming a displacement current. In this period, the current in panel can be expressed as:

$$i_{Cp} = \frac{dq}{dt} = \frac{d(C_P \cdot v_S)}{dt} \tag{2}$$

In this case, panel capacitance $C_p$ should be considered as a time-varying. Hence, the current flowing through the panel can be obtained as:

$$i_{Cp} = C_p \frac{dv_S}{dt} + v_S \frac{dC_p}{dt} \tag{3}$$

As the equation (3), during the discharging period, panel current can be described as the sum of displacement currents due to the variation of applied voltage and discharging currents due to the igniting of the panel capacitance. Typically, the panel total capacitance $C_p$ is increased with the panel size.

For a 40-inch-diagonal AC-PDP, that value is approximately 100 [nF]. In addition, the values of $C_p$ may be slightly affected by wall charge [10]-[15]. When a sustaining pulse is applied to the electrodes, the energy $W$ supplied from a dc source can be written as:

$$W = C_p V_S^2 \tag{4}$$

Where $V_S$ is the supplied voltage [5].

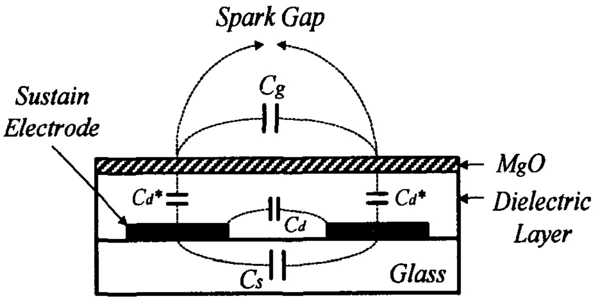


Fig. 1. A simplified equivalent structure of AC-PDP.

In usual drive circuits, the energy $W$ is almost dissipated in the non-ideal resistance of the wire, electrode, and on-resistance of the power MOSFETs. For driving a large-size panel with large panel capacitance $C_p$ in high frequency, high voltage application, the energy loss will be increased and better thermal design is required [10]-[15].

In this paper, an efficient sustain driver with an energy recovery circuit employing boost-up function is presented to achieve suitable rise-time for ADS driving method and to improve the recovery efficiency, regardless of the variation of panel capacitance. The principle of operation, features, and simulated results are illustrated and verified on a 7.5 inch diagonal panel at 200 kHz operating frequency.

## II. PROPOSED SUSTAIN DRIVER FOR AC-PDP

### A. Configuration

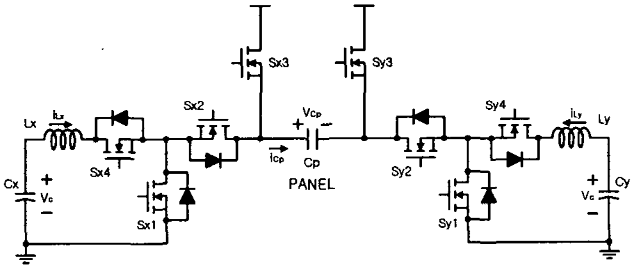


Fig. 2. Proposed sustain driver employing an energy recovery faculty.

Fig. 2 shows the configuration of proposed sustain circuit for driving AC-PDP. On each side of the panel, it consists of four Power MOSFETs with their internal diodes ($Sx_1$, $Sx_2$, $Sx_4$) and without one ($Sx_3$), respectively. Inductor ($L_x$) is used to recovery energy from the panel and to boost up the stored energy in the external capacitor $C_x$ in resonance manner. An internal diode of $Sx_2$ is used to transfer the stored energy in inductor to the panel as soon as the $Sx_1$ is turned off and to block the extra current from dc source. Detailed proposed circuit operations are explained in the next section.

### B. Principle of Operation

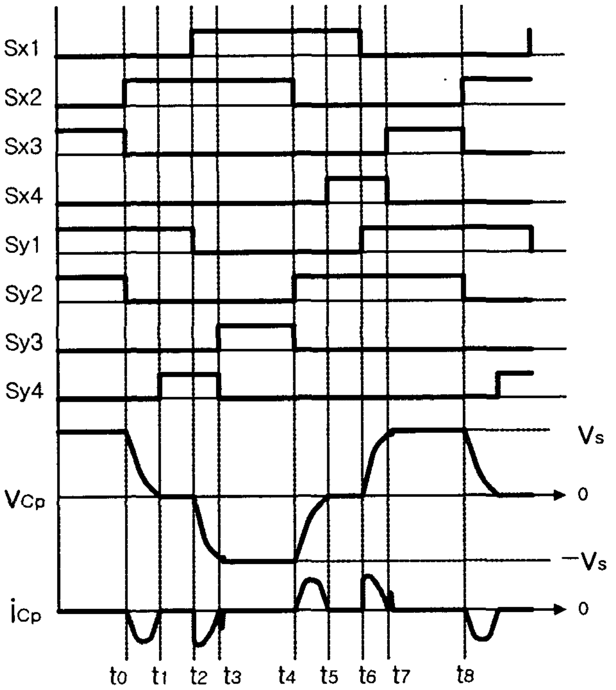


Fig. 3. Operational waveforms.

To simplify the circuit analysis, we ignore the effect of discharging current and assume the value of $C_P$ is constant. Voltage across the external capacitor $C_X$ and $C_Y$ are constant as $V_C$. All components are ideal, and electrodes resistance is neglected. Because each sustain driver has the same operation, we only consider on a half cycle. The left and the right-side drivers can be operated independently so it is not restricted to symmetrical operation. Shown in Fig. 3 is the operational waveforms of proposed sustain driver employing an energy recovery circuit. The upper eight signals in this figure are the respective driving signals of $Sx_1$ - $Sx_4$ and $Sy_1$ - $Sy_4$. Operating principles of a half cycle, $t_0$ - $t_4$, will be explained.

Mode 0 (Before $t_0$): Before $t_0$, $Sx_3$, $Sy_2$, and $Sy_1$ are conducting; therefore, voltage across the panel is maintained as $V_S$. And the current flowing through the panel is null. This mode is shown in Fig. 4(a).

Mode 1 ($t_0$ - $t_1$): At $t_0$, $Sx_3$ and $Sy_2$ are turned off. $Sx_2$ closes to recover the energy in the PDP. In this time, displacement current starts to flow through the inductor $L_x$ and stores the energy in the external capacitor $C_x$ in resonant manner, as indicated by the bold line in Fig. 4(b). During this mode, due to resonance between $C_P$ and $L_x$, voltage across the panel is changed from $V_S$ to zero. Thanks to the series connected inductor $L_x$, $Sx_2$ can be turned on at zero-voltage.

Mode 2 ($t_1$ - $t_2$): At $t_1$, $Sy_1$ is still conducting. When switch $Sy_4$ is closed for this mode, inductor current starts to rise, and energy is stored in the inductor $L_y$, as illustrated by the bold line in Fig. 4(c).

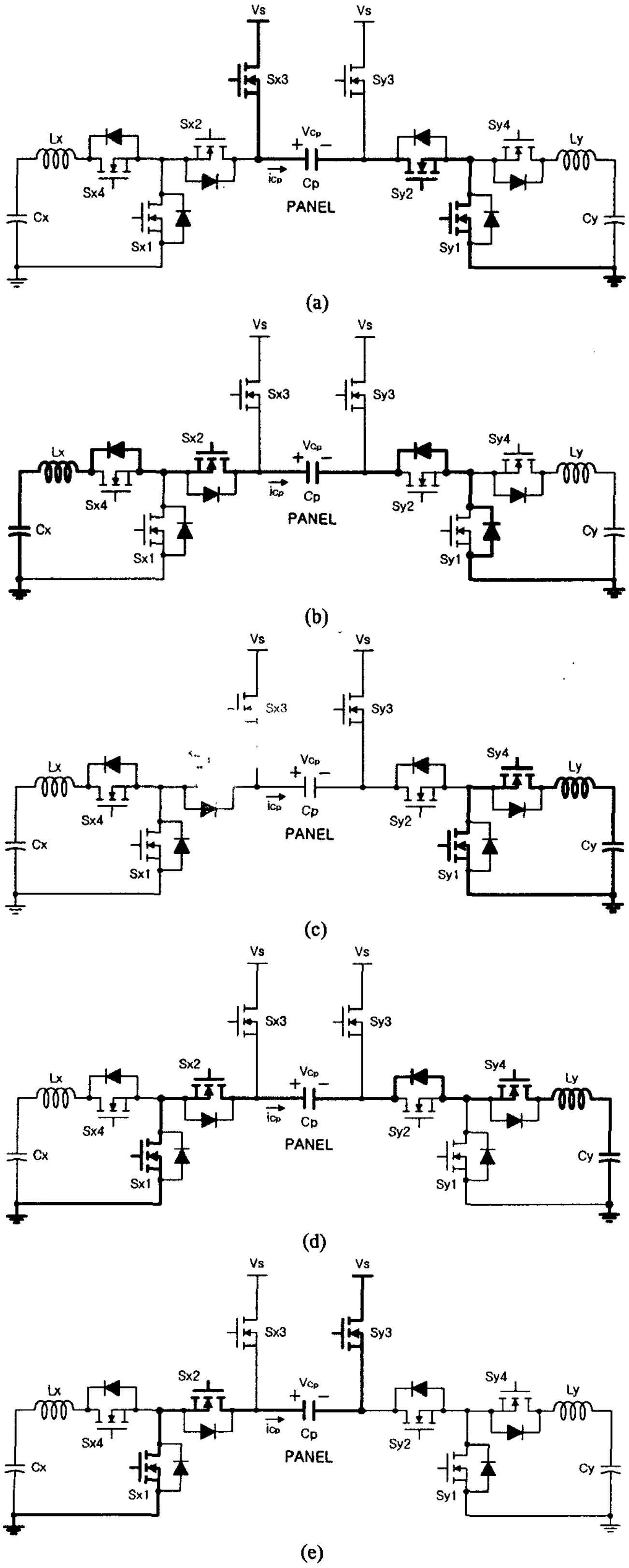


Fig. 4. Operational modes.

(a) Mode 0. (b) Mode 1. (c) Mode 2. (d) Mode 3. (e) Mode 4.

Mode 3 ($t_2$ - $t_3$): At $t_2$, $Sx_1$ is turned on, and $Sy_1$ is in contrast. As soon as $Sy_1$ is turned off, the stored energy in the inductor $L_y$ is instantaneously transferred to the panel through the anti-parallel diode of $Sy_2$ with a faster rise-time. Consequently, the sum of voltage across the inductor and external capacitor is applied to the panel. Voltage across the panel can be stepped up by varying the duty cycle of $Sy_1$ and $Sy_4$. During this mode, transferred current to the panel, a much higher rms current rather than that of the resonant current waveform, flowing through the anti-parallel diode of $Sy_2$ would guarantee the faster rise time of voltage acrross the panel. Current flowing through the panel is given by:

Mode 4 ($t_3$ - $t_4$): At $t_3$, $Sy_4$ is turned off, $Sy_3$ is closed, then voltage across the panel is raised up to negative $Vs$. In this mode, $Sx_1$ and $Sx_2$ are continuously conducting. If the amplitude of pre-charged voltage is as near as the value of negative $Vs$, the input current supplied from the dc-source is considerably reduced. In other words, a fast and exact pre-charging during the prior mode also guarantees the higher recovery efficiency. The next mode will repeat as the mentioned above.

## III. EXPERIMENTAL RESULTS

Fig. 5 shows the experimental set-up of proposed sustain driver equipped with an energy recovery circuit. The specifications of components are listed in Table I. In the experiment, each control signal is generated by the ALTERA using VHDL.

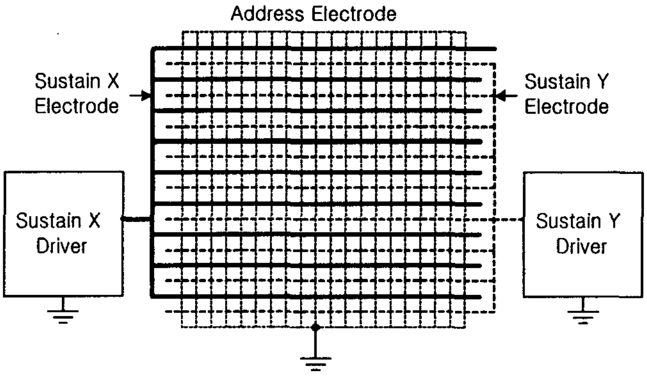
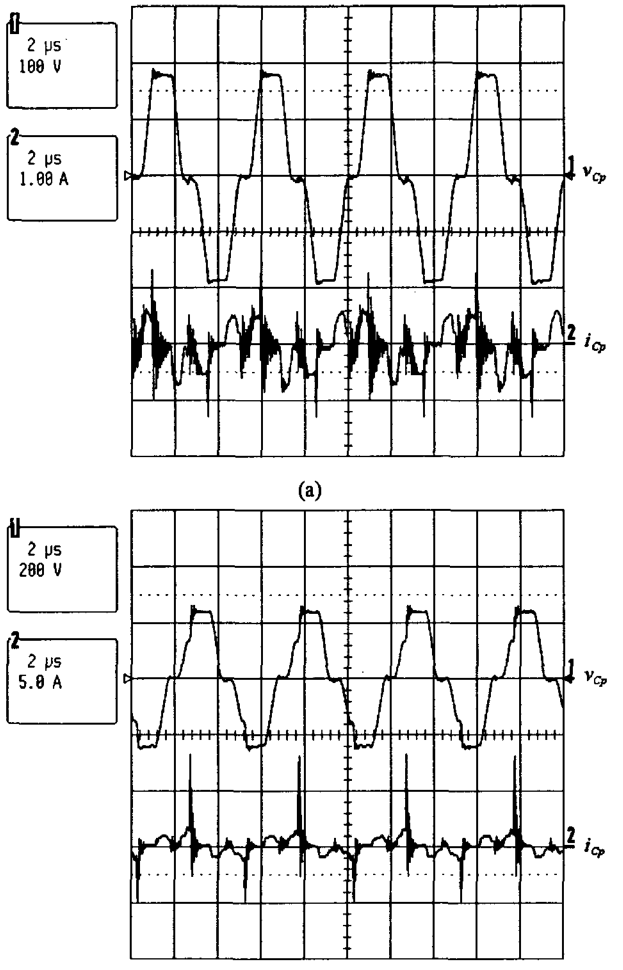


Fig. 5. Configuration of experimental set-up.

Table I
Components list of proposed sustain driver

| Items | Symbol | Value or Type |
|---|---|---|
| **Panel** | Cp | AC PDP<br>7.5 [inch], Xe=6 [%], 500 [Torr] |
| **Power MOSFET** | Sx1-Sx4<br>Sy1-Sy4 | IRFP460 |
| **Inductor** | Lx, Ly | 20 µH / Aircore |
| **External capacitor** | Cx, Cy | 5 µF / Metallized Polyester Film |
| **Gate Amp** | - | TLP250 / Photocoupler |
| **Signal Generation** | - | EPM7064LC84 using VHDL |

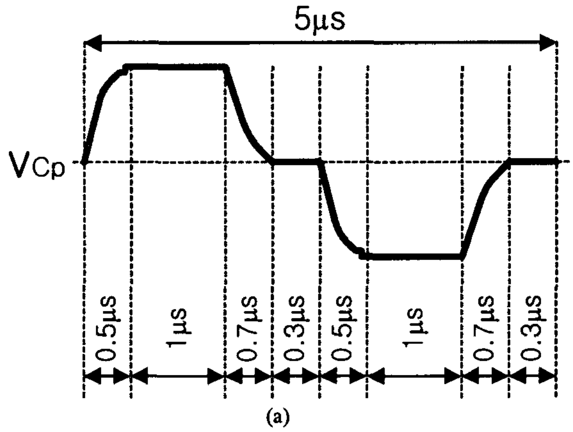


(b)

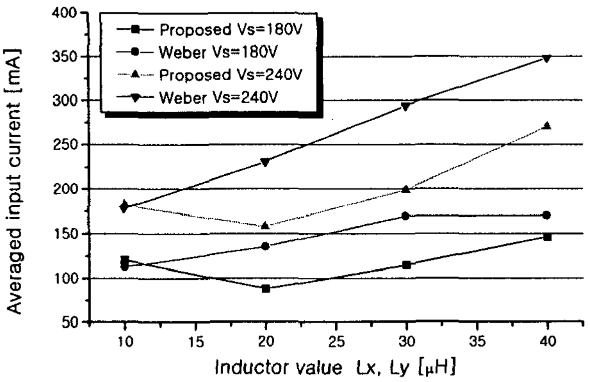
Fig. 6. Experimental waveform of voltage across and current flowing through the panel. (a) Before igniting. (b) After igniting with visible light.

Fig. 6(a) and (b) show the experimental waveforms of proposed sustain driver before and after igniting, respectively. Fig. 6(a) shows the voltage across and the current flowing through the panel, when no light emitted. In this case, only displacement current is flowing through the panel due to the variation of applied voltage. In the plasma display panel, when voltage across the panel is increased up to discharging inception level, the panel will start to ignite the pixels appearing visible light. In this moment, discharging current flows through the panel in addition to the displacement component as shown in Fig. 6(b), and we can find that voltage across the panel is slightly affected by the gas discharging. Since we do not considered any driving voltages added from an address driver, which could influence the sustain voltage of the next display period, higher voltage, i.e., over 240V is required to ignite the panel.

The averaged input current of the proposed sustain driver was compared with the presentable Weber's circuit. To assess the ability of each driver under the same test condition, we limited the period of sustain, rise, and fall as 1 [µs], 500[ns], and 700 [ns], respectively. Each control signal was generated according to the shape in Fig. 7(a). It was compared using the simulated result. In the simulation, only the inductor value was changed. In the case of proposed circuit in Fig. 7(b), before igniting the averaged input current is shown in the range of 87 [mA] to 146 [mA] regardless of the variation of inductor value. But after igniting it is increased up to 270 [mA] with the inductor value of 40 [µH]. On the other hand, the conventional driver requires higher input current than the proposed. When panel is ignitng, almost 350 [mA] is needed. Of cause, if there is no limitation to the voltage rise period, it can save a large amount of energy reducing the requied input curmet. But when it has the limitation to the voltage rise-time to be suitable for ADS (address display period separated) method, the conventional sustain driver does not have sufficient performance. To solve this problem, lower inductor value can be used; however, notice that higher inductor value guarantees higher efficiency in the case of resonent type sustain driver. In the proposed sustain driver, rise time is appeared in the range of 43 [ns] to 63 [ns] regardless of the panel conditions. As a result, it can increase the sustain period near 430 [ns].



(a)



(b)

Fig. 7. Comparison of averaged input current of each sustain driver, and its test condition. (a) Period limitation for comparison. (b) Simulated results.

## IV. CONCLUSION

In this paper, an efficient AC-PDP sustain driver employing boost-up function is proposed to achieve a faster rise-time in order to be suitable to widely used the address display period separated (ADS) driving method. The proposed circuit improves the recovery efficiency regardless of the variation of the panel ON-OFF conditions. The most outstanding characteristic of proposed driver is to employ the boost-up period resulted in fast rise-time of panel voltage. In the experiment, it increased the extra period up to 430 [ns] without efficiency drop. The principle of operation, features, and simulated results are illustrated and verified on a 7.5-inch diagonal panel at 200 [kHz] operating frequency based on experimental prototype.

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