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High Performance AC-PDP Sustain Driver with Low switching Loss

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낮은 스위칭 손실을 가지는 고성능 AC-PDP 구동 회로에 관한 연구

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ABSTRACT

When the plasma panel is used as a display, frequent discharging are made to occur by alternatively charging each side of the panel to a critical voltage, which causes repeated gas discharges to occur. In this paper, an efficient sustain driver is proposed to achieve a faster rise-time in order to be suitable to widely used ADS driving method. The proposed circuit increases an operational margin up to 20 % compared with conventional approaches improving the recovery efficiency regardless of the variation of panel capacitance. Thanks to the increased operational margin, the brightness decrease problem can be solved without a limitation to sustain pulse width. The principle of operation, and features are illustrated, and verified on a 7.5 inch diagonal panel at 200 kHz operating frequency – based on experimental prototype.

Key words: Plasma display panel, Sustain driver, ADS (Address Display period Separated) method.

I. INTRODUCTION

The simplicity and durability of plasma displays makes this technology a fascinating candidate for a display industry. Early, the PDP was designed as a DC panel equipped with the connected diodes between row and column electrodes. Without any memory and with line at a time addressing, their panels are suffered from a lack of brightness. Moreover, the lifetime of the panels was rather shorter because of electron and ion collision of the electrodes. The settlement in both the brightness and lifetime problem came with the development of the AC surface discharge panels with sub-field addressing. Advantages of AC plasma displays include ease of producing large panels, rapid response, long lifetime, thinness, and wide viewing angle. Thanks to these merits, AC-PDP is considered to be the best one for manufacturing a wide, flat HDTV display [1]-[5].

In the driving of plasma display panel, frequent discharges are happened by alternatively charging each side of the panel to a critical voltage, which causes repeated gas discharges to occur. This alternating voltage is called the sustain voltage, and it is produced by the sustain driver. If a sustain driver has no energy recovery function, $2C_pV_s^2$ is dissipated in a complete sustain cycle. Because each side of the panel is charged to V_s and subsequently discharged to ground. It is, moreover, proportional to the switching frequency.

For widely used ADS driving method, the address and sustain period is separated. Eight sub-fields compose one TV frame. Each sub-field is consisted of reset, address, and sustain periods, respectively. Each display period is arranged according to the binary sequence 2^0-2^7. Consequently, 2^8 gray levels for each color (Red, Green, Blue) can be expressed with an 8 bits sequence [4]-[11].

In order to reduce false contour, to increase scan lines and sub-fields is one solution, but this approach cannot obtain sufficient brightness due to the reduction of sustain period [12]. To drive HDTV class PDP with same brightness level as high as commonly used VGA class PDP, several methods have been presented to solve those brightness decrease problem [13]-[15]. Among them, increasing the number of sustain discharge by decreasing sustain pulse period is commonly used [15]. However, if the width of sustain pulses is limited due to sustain voltage rise time, operation margin tends to be reduced [16]-[18]. If the conventional sustain driver that depends only upon a resonance between an intrinsic panel capacitance and an external inductor is equipped with the panel, the resonant time, i.e., rise-time of voltage across the panel, limits the sustain pulse width. As a result, 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 sustain driver, because the larger inductor value guarantees the higher energy recovery efficiency.

In this paper, a novel efficient sustain driver employing an additional step-up period is proposed to achieve fast rise-time. It solves brightness decrease problem with an increased operational margin. It also improves the recovery efficiency regardless of the variation of panel capacitance. As results, proposed sustain driver is suitable for commonly used ADS method. In addition, it has a simple structure compared with conventional approaches, and soft-transition of all active switches can be possible resulted in considerable reduction of switching losses. 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. CONVENTIONAL APPROACH & PROPOSED SUSTAIN DRIVER

First, a circuit model of the presentable prior sustain driver will be analyzed to assess the proposed driver. The reasons why larger than 20 percents operational margin is possible with this new sustain driver will be explained, and design guidelines will be given. Next a constructed prototype of the new sustain driver will be discussed, and verified through the experimental results.

Ideal sustain driver circuits will be presented first to show the basic operation of the both sustain drivers, given ideal components. As would be expressed, given ideal components, the conventional circuit has 100 percents recovery efficiency in charging and discharging a capacitive load. The schematic of the ideal sustain driver circuit is shown in Fig. 1(a), and in Fig. 1(b) are shown the output voltage and panel current waveform expected for this circuit as the eight switches are opened and closed through the eight switching states is explained in detail below, where it is assumed that prior to state 1, $V_{Cx(y)}$ is at $V_S/2$ where V_S is the sustain power supply voltage, V_{Cp} is at positive V_S, S_{x1} and S_{y4} are closed.

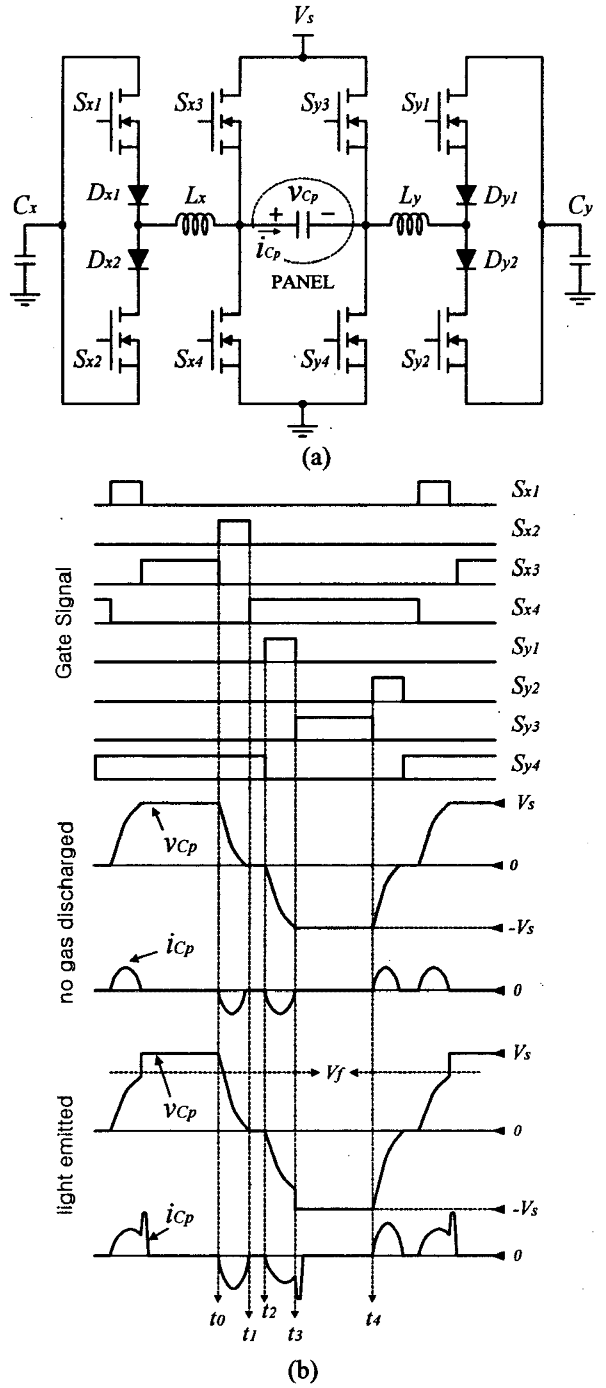
State 1 [t_0- t_1]: To start, S_{x2} closes, and S_{x3} opens. With S_{x2} closed, L_x and C_P form a series resonant circuit, which has a forcing voltage of V_{Cx}= $V_S/2$. V_{Cp} then falls to ground, at which point I_{Lx} is zero, and D_{x2} becomes reverse biased. Alternatively, diode D_{x2} could be eliminated and S_{x2} opened when V_{Cp} falls to zero at the point where I_{Lx} is zero.

State 2 [t_1 - t_2]: S_{x4} is closed to clamp V_{Cp} at ground while an identical driver on the opposite side of the panel drives the opposite side to V_S and a discharge current then flows in S_{x4} if any pixels are "ON".

State 3 [t_2- t_3]: With S_{y1} closed L_y and C_P again form a series resonant circuit, which has a forcing voltage of V_{Cy}= $V_S/2$. V_{Cp} then rises to V_S, at which point I_{Ly} is zero, and D_{y1} becomes reverse biased. Alternatively, diode D_{y1} could be eliminated and S_{y1} opened when V_{Cp} rises to V_S at the point where I_{Ly} is zero.

State 4 [t_3- t_4]: S_{y3} is closed to clamp V_{Cp} at V_S and to provide a discharge current path for any "ON" pixels.

The conventional sustain driver shown in Fig. 1(a) basically utilizes the resonance between an external inductor and intrinsic capacitance of the PDP. If the panel capacitance C_p is always constant and there is no limitation to sustain pulse width to solve the brightness decrease problem, this circuit will save large amount of energy. Since C_p is always changing according to the pixel's "ON/OFF" conditions, a complete resonance between the panel capacitance and external inductor is difficult. Therefore, energy recovery efficiency will be reduced. This problem can be alleviated by fast resonant time reducing inductor value. But this is not suitable for the resonant type sustain driver, since the larger inductor value guarantees the higher energy recovery efficiency.



(a)

(b)

Fig. 1. Conventional sustain driver for AC-PDP and its operational waveforms. (a) Configuration. (b) Key waveforms.

Fig. 2(a) shows a configuration of proposed sustain driver employing a step-up period in sustain mode operation. On each side of the panel, it consists of three Power MOSFETs with their internal diodes. Inductor L_x (and L_y) is used to resonate with panel in order to recovery energy from the panel. By means of switching operation of S_{x1} (or S_{y1}) and S_{x2} (or S_{y2}), the external capacitors recovery the energy from the intrinsic capacitance of panel via the inductor. When the S_{x1} (or S_{y1}) is closed, the inductor steps up the energy, and then transfers them to the panel as soon as the S_{x1} (or S_{y1}) is opened. Because of the boost-up faculty, it can take a fast rise time resulted in the increased operational margin. The internal diode of S_{x1} (or S_{y1}) also plays a role to block the current path when it is operated in reset and address periods. Detailed proposed circuit operations are explained in the following. To simplify the circuit analysis, we assume that all components are ideal, and equivalent resistance of wire, electrode, and on-resistance of switches are neglected. Because each sustain driver has the same operation, we only consider on a half cycle. The left-side and right-side drivers can be operated independently so it is not restricted to symmetrical operation. Fig. 2(b) shows the operational waveforms of proposed circuit. The upper six waveforms are the respective driving signals of S_{x1} - S_{x3} and S_{y1} - S_{y3}. According to the control signals, voltage across and current flowing through the panel are illustrated. When light is emitted, voltage across the panel is affected by the discharging current. Operating principles of the half cycle, t_0 - t_4, are explained. Before t_0, by means of S_{x3} and S_{y1} conducting, voltage across the panel maintains positive Vs. Current flowing through the panel is null.

Mode 1 [t_0 - t_1]: recovery period.

To start at t_0, S_{x3} opens, then the intrinsic capacitance of panel resonates with the inductor via the internal diode of S_{x2}, S_{y1}, and saves the energy to the external capacitance. This recovery resonance is dependent only the natural characteristics of inductance and capacitance. After a complete resonance, voltage across the panel falls to zero. In the case of light emitted, total capacitance of the PDP is larger than that of no gas discharged case; therefore, it needs more additional time for a complete resonance as shown in the lower waveform of Fig. 2(b).

Mode 2 [t_1 - t_2]: Step-up period.

At t_1, S_{y2} closes, then the stored energy in the external capacitor C_y is transferred to the inductor L_y via S_{y2} and S_{y1}. By means of the inductor, S_{y2} can be softly switched at zero voltage. The additional step-up period prepares for the next charging operation accumulating energy to the inductor. The peak of inductor current can be controlled by the duty ratio of S_{y1} and S_{y2}. Current flowing through the inductor is increased until S_{y1} is opened.

Mode 3 [t_2 - t_3]: Energy transferring period.

At t_2, S_{x1} is conducting, while S_{y1} opens. As soon as S_{y1} is turned off, voltage across the inductor inverters its voltage polarity; therefore, the summed voltage, $v_{Cy} + v_{Ly}$ is supplied to the panel. Consequently, the stored energy to the inductor is rapidly transferred to the panel with a fast rise time. The fast rise time guarantees not only an increase of operational margin but also reduced energy losses resulted in high efficiency. It will be verified on the next section.

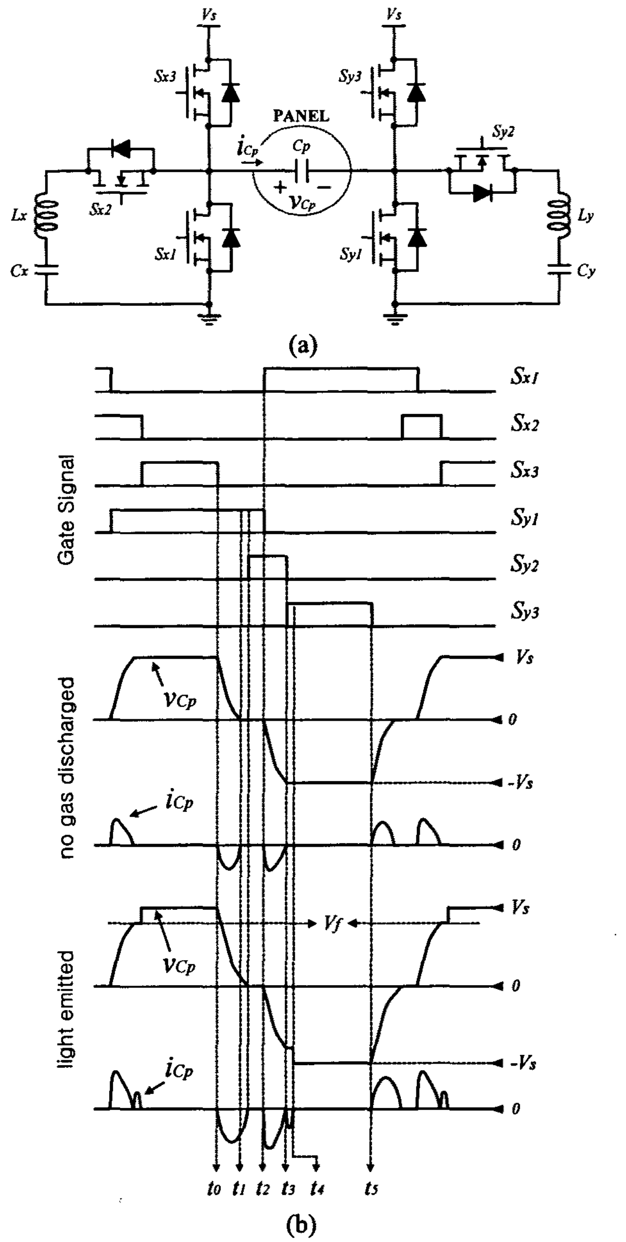


Fig. 2. Proposed sustain drivers for AC-PDP and its operational waveforms. (a) Configuration of proposed circuit. (b) Operational waveforms.

Mode 4 [t_3 - t_4]: Discharging period.

At t_3, S_{y3} closes, and S_{x1} is continuously conducting. When the prior mode is finished, once the panel voltage is equal to that of supply voltage, there is no input current; hence, S_{y3} can be softy turned on, and voltage across the panel maintains Vs. Note that panel characteristics are different from those of general capacitors. Under the discharge inception voltage, only a displacement current is flowing through the panel. Discharging current is only occurred when light is emitted. When voltage across the panel reaches to the discharging inception voltage v_f, the panel ignites flowing discharge current as shown in Fig. 4(d).

Mode 5 [t_4 - t_5]: Sustain period.

From t_4 to t_5, by means of S_{y3} and S_{x1} conducting, voltage across the panel maintains a critical voltage level, i.e., sustain voltage. The next mode repeats the mentioned above operations in sequence.

Fig. 3 shows the equivalent circuit of proposed sustain driver during the energy recovery period. It is equivalent to that of conventional approach.

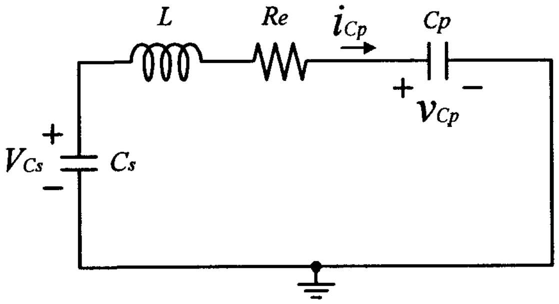


Fig. 3. Equivalent circuit of proposed sustain driver.

In this figure, R_e means the equivalent resistance. To simplify, let's assume that R_e is sufficiently small. Then, voltage across and current flowing through the panel can be expressed as:

$$i_{Cp} = -V_{Cs} \cdot \sqrt{\frac{C_P}{L}} \cdot \sin \frac{1}{\sqrt{LC_P}} \cdot t \qquad (1)$$

$$v_{Cp} = \frac{1}{C_P} \int i_{Cp} \cdot dt = V_{Cs} \left(\cos \frac{1}{\sqrt{LC_P}} \cdot t - 1 \right) \qquad (2)$$

The recovery time τ_r that voltage across the panel completely falls to zero from V_S is given as:

$$\tau_r = \pi \sqrt{LC_P} \qquad (3)$$

On the other hand, the energy transferring time τ_t that voltage across the panel completely rise toward V_S from ground is written as:

$$\tau_t = \frac{\pi}{2} \sqrt{LC_P} \qquad (4)$$

τ_r is equal to that of the conventional circuit. Whereas τ_t is reduced to a half of that of conventional approach. It is the reason why the proposed circuit has a fast rise time. In the case of conventional circuit, energy transferring depends only the natural resonance frequency; therefore, inductor current is zero at the start point of energy transferring. While the inductor current of proposed circuit has peak value by means of the step-up period. As soon as switch (S_{x1} or S_{y1}) is turned off, the accumulated energy to the inductor is fast transferred to the panel. As results, the operational margin can be increased up to approx. 20 [%] compared with conventional circuit.

The following equations may be useful when designing the inductor L_x, L_y and duty ratio of the switches. Because τ_r is double of τ_t, the resonance time should be set by τ_r. From the key waveforms in Fig. 2(b), τ_r is t_1 - t_0. Therefore, the following relation is given:

$$\tau_r = t_1 - t_0 = \pi \sqrt{LC_P} \qquad (5)$$

According to the characteristics of the PDP, operating frequency and panel capacitance are determined; hence, a proper inductor value can be taken. For practical application, operating frequency is in the range of 100 - 200 [kHz].

III. SIMULATED AND EXPERIMENTAL RESULTS

Operational principles of proposed sustain driver is verified on a 7.5-inch-diagonal panel at 200 [kHz] operating frequency based on experimental prototype. The specifications of components are listed in Table I. In the experiment, the control signals of switches are generated by ALTERA using the VHDL.

Table I Specification of components.

Items	Symbol	Value & Type	Manufacturer
Panel	Cp	7.5 inch AC PDP	LG Electronics Inc.
Power MOSFET	Sx1-3, Sy1-3	IRFP460	Inretnational Rectifier
Inductor	Lx, Ly	30 μH / Aircore, respectively	
External capacitor	Cx, Cy	4.7 μF / Metallized Polyester Film, respectively	
Gate Amp	-	TLP250 / Photocoupler	Toshiba
Signal Generator	-	EPM7064LC84 using VHDL	ALTERA

Fig. 4(a) shows the experimental waveforms of voltage across the panel v_{Cp} and the current flowing through panel i_{Cp} with the switching frequency of 200 [kHz]. As mentioned eariler, address and sustain periods are separated in ADS method. Because we do not considered any driving voltages added from an address driver, which could influence the sustain voltage of the next display period, it maintains the address period to ground. Fig. 3(b) is magnified waveform of Fig. 3(a) when it is operated under no gas discharged condition. From the figure, recovery, step-up, energy transferring, and sustain periods can be found. Thanks to the additional step-up function, when $S_{x(y)1}$ is turned off, $V_{Cs(x,y)}$+ $V_{L(x,y)}$ is applied to the panel; therefore, a fast rise-time can be guaranteed and operation margin is increased. Fig. 4(c) shows voltage across and current flowing through the panel when light is emitted. As mentioned earlier, since we do not considered the effect of address driving; therefore, to ignite the plasma higher voltage, i.e., over 230 [V] is required to ignite the panel. From Fig. 4(c), we can find that voltage across the panel is slightly affected by the gas discharging.

Fig. 5 shows the soft-transition of the switches S_{x1} - S_{x3}. The waveforms in Fig. 5(a) through (c) indicate that the switches are controlled at ZCS turn-off. Because of a symmetrical operation, S_{y1} - S_{y3} have the same waveforms. Thanks to these soft-transition, switching loss can be considerably reduced.

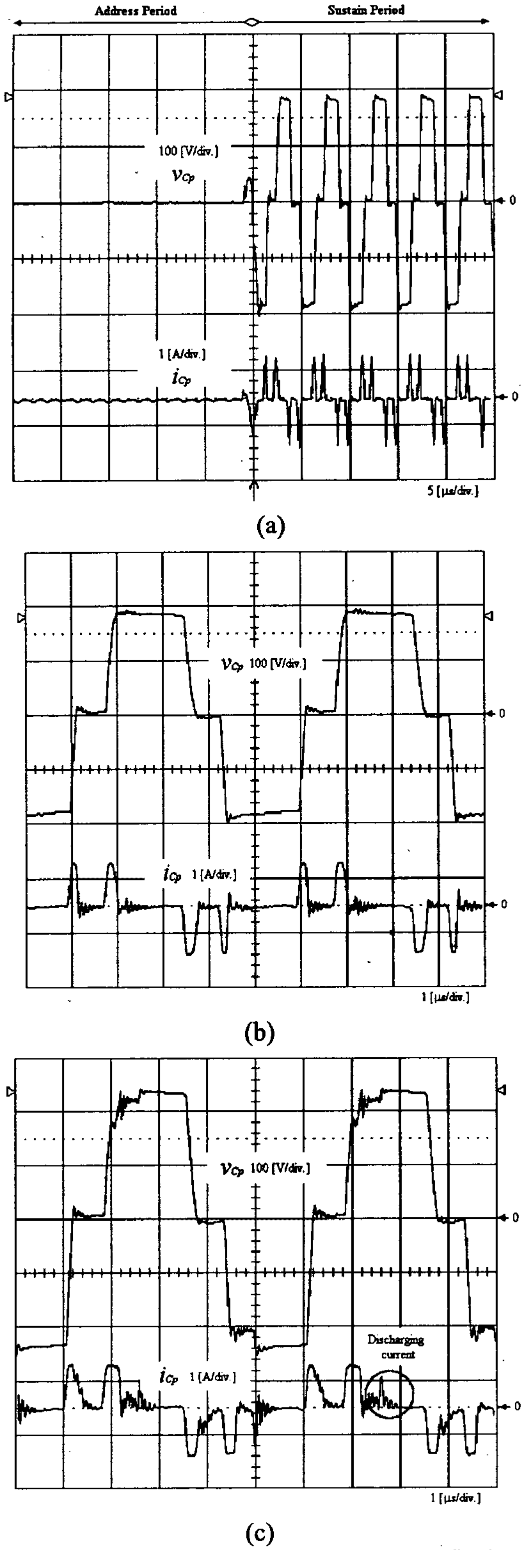


Fig. 4. Experimental waveform of voltage across and current flowing through the panel. (a) Voltage and current of the panel at the boundary between an address and sustain period in ADS method. (b) No gas discharged, 180 V. (c) Light emitted, 240 V.

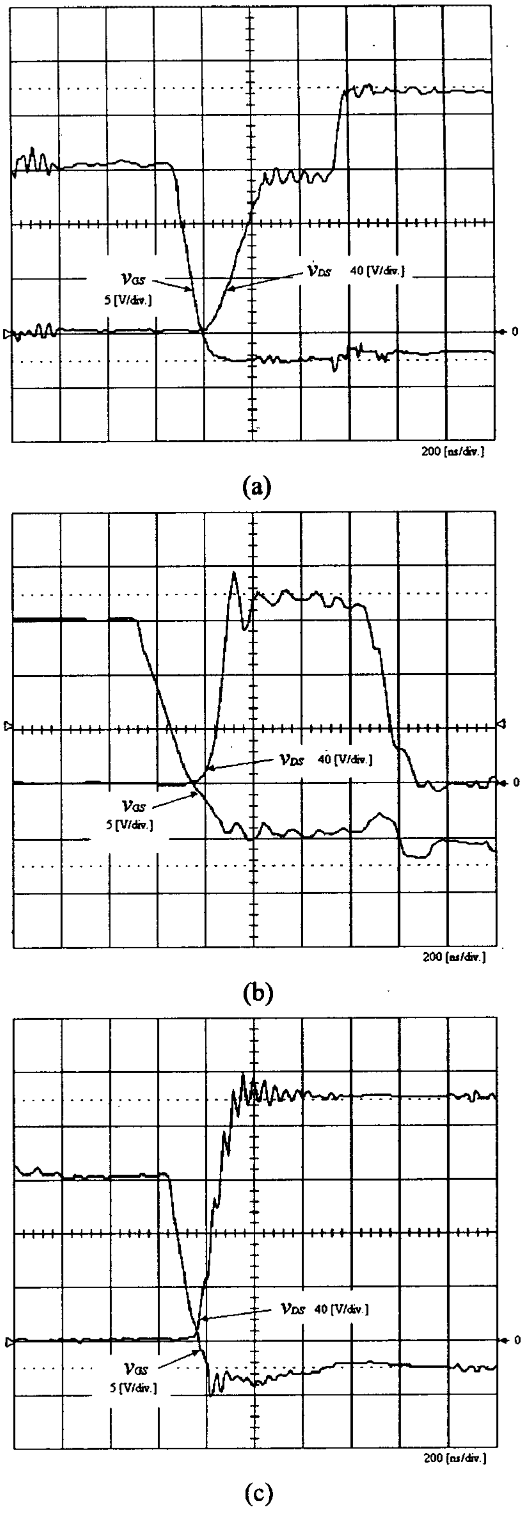


Fig. 5. Experimental waveforms of switches S_{x1}-S_{x3}. (a) Drain-to-Source and Drain-to-Gate voltage of S_{x1}. (b) Drain-to-Source and Drain-to-Gate voltage of S_{x2}. (c) Drain-to-Source and Drain-to-Gate voltage of S_{x3}.

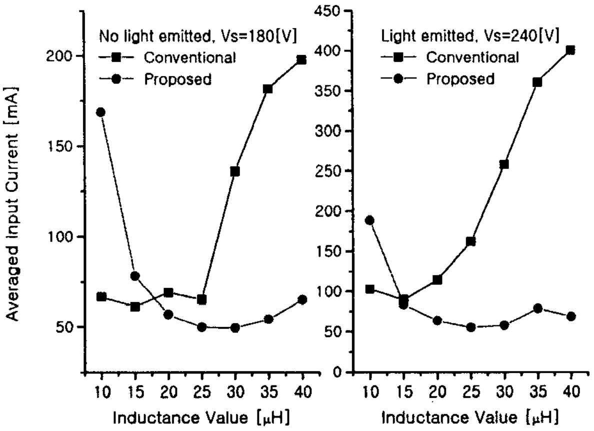


Fig. 6. Comparison of averaged input current according to the variation of inductance.

According to the variation of inductor value, averaged input currents of proposed scheme are compared with them of the conventional circuit. In this comparison, each energy transferring period is limited to 0.5 [µs], and every sustain period is set to 1 [µs]. A half cycle finishes on 2.5 [µs]. If a sufficient resonant time is given to the conventional approach, energy efficiency will be proportional to the increase of inductance value. Generally, in the case of conventional circuit depend upon a resonance between the panel and external inductor, the larger value of inductor guarantees the higher energy recovery efficiency. However, since it was limited to 0.5 [µs] in the comparison, averaged input currents are increased with the inductor value. Moreover, total panel capacitance is always changing according to the pixel's on-off conditions. Consequently, when panel is ignited, the averaged input current will be considerably increased as shown in Fig. 7. On the other hand, proposed circuit requires nearly constant input current regardless of the variation of panel capacitance. From the graph, an averaged input current of the conventional circuit has the smallest value, i.e., 61.692 [mA], when the value of inductor is 15 [µH]. This can be compared to 30 [µH] of proposed circuit. At this value, the averaged input current of proposed circuit is 49.398 [mA]. It means that proposed circuit can improve the energy recovery efficiency by means of using of a larger inductor without a limitation of the resonant time. Compared with the conventional approach, operation margin can be increased upto 20 [%] of the conventional approach without reducing inductor value resulted in efficiency decrease. Notice that the panel capacitance is always changing according to the pixel's "ON-OFF" conditions. As a result, the proposed sustain driver is more suitable for practical ADS method in the PDP application.

VI. CONCLUSION

A novel efficient sustain driver employing an additional step-up period has been presented to increase the operational margin that is sufficient in commonly used ADS driving method. It improves the recovery efficiency without the limitation of a resonant time, and has a simple structure compared with conventional approach. Regardless of the variation of panel capacitance, operation margin of the proposed driver is increased up to 20 [%] compared with conventional approach that depend only on the resonance between a panel capacitance and an external inductor. Thanks to the increased operational margin, the brightness decrease problem can be solved without a limitation to sustain pulse width. The principle of operation, features are illustrated, and verified on a 7.5-inch-diagonal panel based on experimental prototype with 200 [kHz] operating frequency.

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