

Novel Energy-Recovery Driving Circuit for Plasma Display Panel using Regenerative Transformer

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Abstract—A novel energy-recovery driver is proposed to efficiently drive a plasma display panel (PDP) in the sustaining operation. The proposed circuit can achieve zero-voltage switching (ZVS) for clamping switches and zero-current switching (ZCS) for resonant switches and diodes for all modes of operation. The charging/discharging energy of the panel capacitance can be recovered through the regenerative transformer without additional components.

I. INTRODUCTION

The PDP is praised for its large screen size, wide viewing angle, long life, high contrast ratio, thinness, etc. It is likely that the PDP will soon become consumer-affordable wall-hanging color TVs with large diagonal measurements.

The PDP has inherent capacitance during voltage transients [1]. Fig. 1 shows the equivalent model of the PDP with a simple driver to generate AC driving voltage-pulses between the sustain-electrodes. In general, the sustain pulses are AC rectangular pulses, its voltage (V_s) is above 180V, and its frequency (f) is in the range of 100-200 kHz. The panel capacitance (C_p) is above several tens nF. During the charging/discharging of the panel capacitance, the energy of $C_p V_s^2$ for each cycle is dissipated through the driving circuit and the PDP. The power loss of $2 \cdot f \cdot C_p V_s^2$ is too large to be acceptable for home-use TVs. And furthermore, the charging/discharging surge current causes serious resonance and electromagnetic interference (EMI) noise.

In order to make the transient soft and recover the capacitive energy, several energy-recovery circuits have been proposed [2]~[4]. Fig. 2 shows a series resonant energy-recovery circuit [2][3]. This circuit is widely used. However, it has some drawbacks. Firstly, large electrolytic capacitors must be used to stabilize the voltage at $V_s/2$. Secondly, the clamping switches (S1~S4) cannot be operated with 100% ZVS because of a damping factor which is the

conduction loss of resonant circuit. Thirdly, the critical gating sequence of the clamping switches (S1, S3) is required for proper PDP operation.

This work proposes a novel energy-recovery circuit, which overcomes the drawbacks of the prior circuit mentioned above.

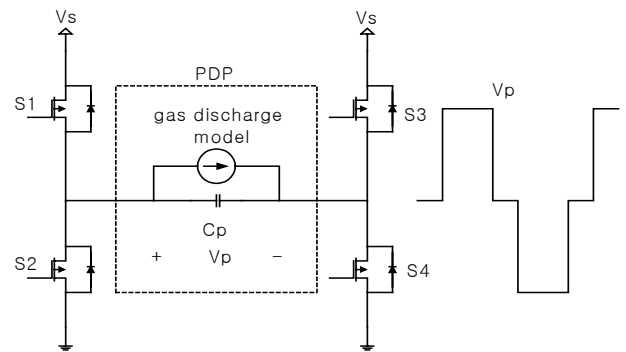


Fig. 1 Equivalent model of PDP with a simple driver

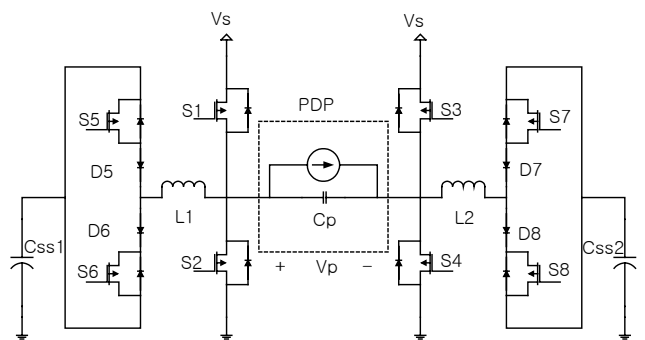


Fig. 2 Prior circuit: series resonant energy-recovery circuit [2][3]

II. PROPOSED CIRCUIT

A. Proposed circuit

Fig. 3 shows the basic type of a proposed circuit. The proposed circuit consists of clamping switches (S1~S4),

resonant switches (S5~S8), diodes (D5~D8), resonant inductors (L1, L2) and regenerative transformers (Tx1, Tx2). The leakage inductance of transformer can be used as resonant inductors. The regenerative transformer is very small because it operates at a high frequency only during the charging/discharging transients. The transformer recovers the capacitive energy to the input voltage source during the charging/discharging resonance. Furthermore, the secondary voltage of the transformer determines resonant condition. The proposed circuit can achieve 100% ZVS for clamping switches regardless of circuit's conduction loss. Therefore, the gating sequence of the clamping switches is easily implemented by sensing the drain-source voltage of switches [5].

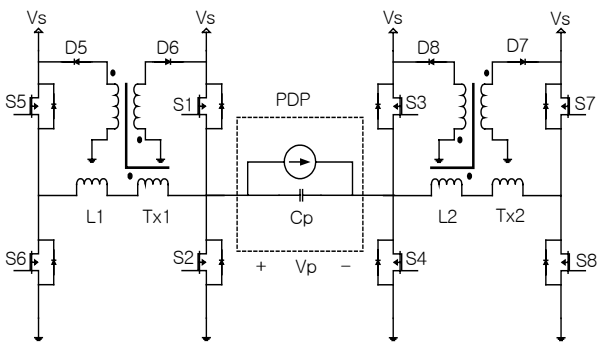


Fig. 3 Proposed circuit (basic type)

B. Mode analysis

Fig. 4 shows the gating signals and key waveforms of the proposed circuit, and the circuit operations of each mode are as follows.

Mode 1 [t0~t1]: The voltage of panel capacitance (V_p) is zero. At time t_0 , S5 is turned on. Input voltage (V_s)-S5-resonant inductor (L)-transformer's voltage (V_{tx})-panel capacitor (C_p) form series resonant circuit. If V_{tx} is lower than half of V_s , V_p becomes V_s before the inductor current (I_{ind}) reaches zero. The transformer's current is recovered through D5.

Mode 2 [t1~t2]: At time t_1 , the body diode of S1 is turned on. V_p is clamped to V_s . At this time, S1 is turned on under complete ZVS condition and S5-L- V_{tx} -S1 form a closed circuit. I_{ind} decreases linearly. The transformer's current is also recovered through D5.

Mode 3 [t2~t3]: I_{ind} becomes zero. D5 is naturally turned off. At this time, S5 is turned off under ZCS condition. S1 clamps V_p to V_s for proper PDP gas discharge.

Mode 4 [t3~t4]: V_p is V_s . At time t_3 , S6 is turned on. S6-L- V_{tx} - C_p form series resonant circuit. If V_{tx} is lower than half of V_s , V_p becomes zero before I_{ind} reaches zero. The transformer's current is recovered through D6.

Mode 5 [t4~t5]: At time t_4 , the body diode of S2 is turned

on. V_p is clamped to zero. At this time, S2 is turned on under ZVS condition and S6-L- V_{tx} -S2 form a closed circuit. I_{ind} decreases linearly. The transformer's current is also recovered through D6.

Mode 6 [t5~t6]: I_{ind} becomes zero. D6 is naturally turned off. At this time, S6 is turned off under ZCS condition. S2 clamps V_p to zero.

The opposite side circuit operates in the same modes as above.

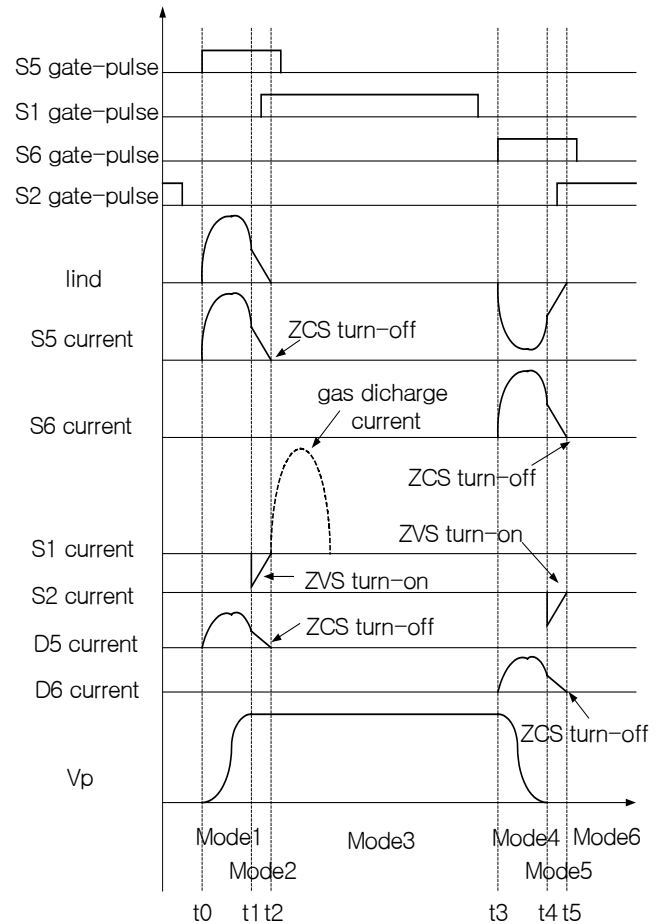


Fig. 4 Gating signals and key waveforms of the proposed circuit

III. VARIATIONS OF PROPOSED CIRCUIT

The current stress of S5, S6 and the voltage stress of D5, D6 can be reduced by modifying the basic type. The voltage and current stresses are approximately the half of the basic type. Fig. 5 shows the circuit variations. The center-tap type can be designed respectively at charging and discharging transient. The forward type is a simple structure in comparison with the center-tap type. Type (a) and (b) operate in the same way of the basic type by using the input voltage feedback. Type (c) operates differently by using the capacitor voltage feedback.

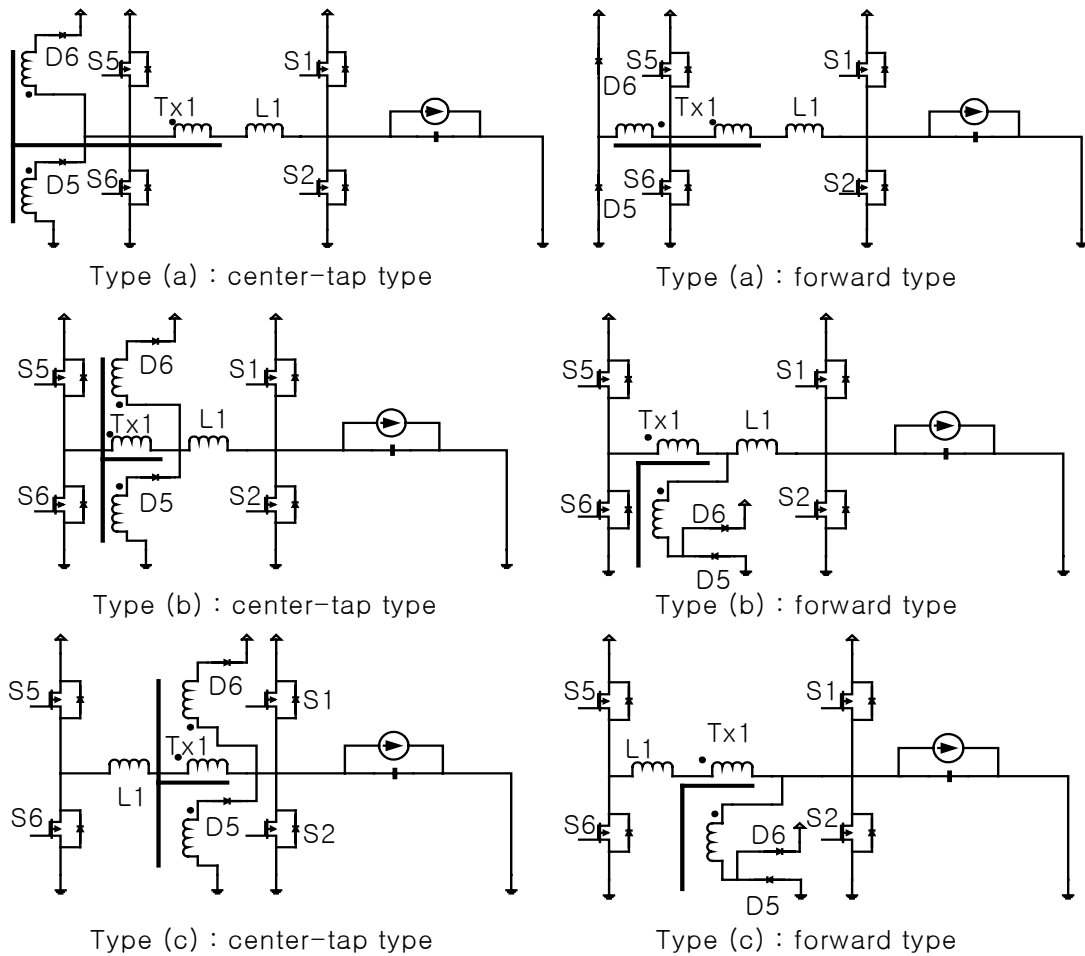


Fig. 5 Circuit variations

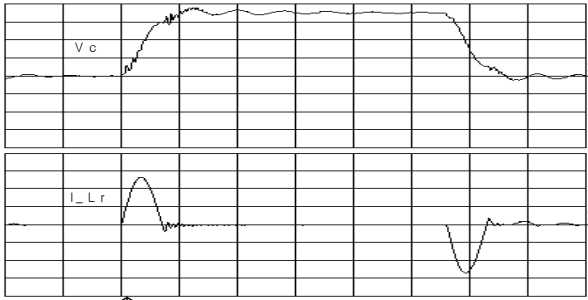
The advantage of type (b) is that the current stress of primary transformer is the half of type (a)'s one. The additional advantage of type (c) is that the current stress of resonant inductor is the half of type (b)'s one.

IV. EXPERIMENTAL RESULTS

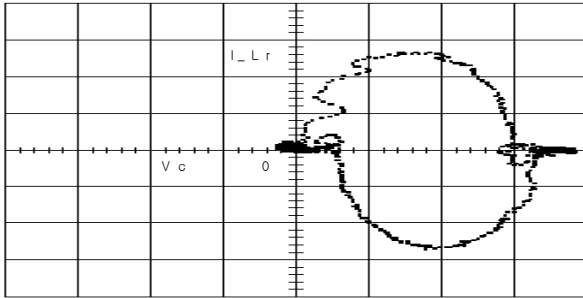
Fig. 6 and 7 show the panel voltage (V_p), the inductor current (I_{Lr}), state-plane trajectory (V_p, I_{Lr}), the drain - source voltage (V_{ds}), and gate - source voltage (V_{gs}) of main switch (S1). The panel capacitance is 80 nF. The resonant inductance is 300 nH which is linear inductor or the leakage inductance of the transformer. The switching frequency is 100 kHz. The input voltage (V_s) is 180V. The proposed experimental hardware is built for the forward type (a).

As shown in Fig. 6, the conventional energy recovery circuit can not charge panel capacitance up to input voltage (V_s) and discharge up to ground level (0) because of parasitic resistance and active device's forward voltage-drop. This causes hard switching of main switch and oscillations of panel voltage waveform.

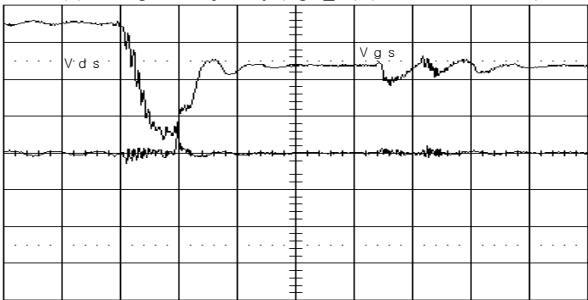
As shown in Fig. 7, the proposed energy recovery circuit can supply additional resonant energy by designing the turns-ratio of transformer. Therefore, V_p is clamped to V_s and zero before I_{ind} reaches zero and, then, I_{ind} becomes zero regardless of resonant energy loss. 100 % ZVS of S1,S2 and ZCS of S5, S6, D5, D6 are achieved. The negative current is caused by the reverse-recovery of D5, D6. It can be improved by using fast recovery diodes and ferrite bead core.



(a) Panel voltage(V_p), inductor current(I_{Lr}) (50V/div. 10A/div. 1usec/div.)

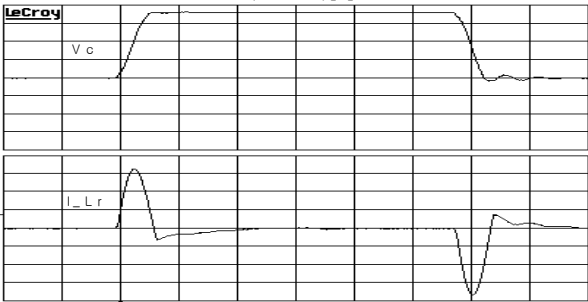


(b) State-plane trajectory (V_p, I_{Lr}) (50V/div. 10A/div.)

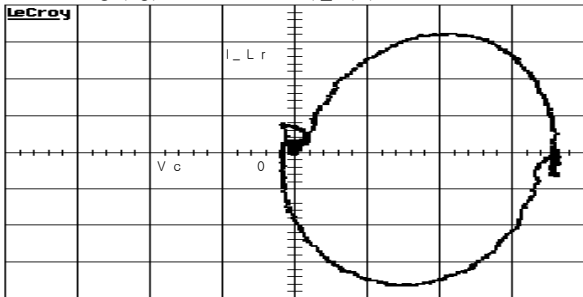


(c) V_{ds} V_{gs} of S1 (50V/div. 5V/div. 1usec/div.)

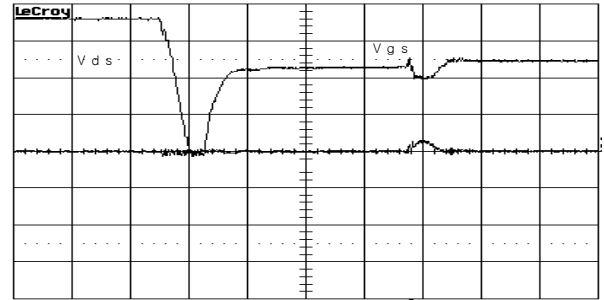
Fig. 6 Experimental waveform of conventional energy recovery circuit (Webber)[2]



(a) Panel voltage(V_p), inductor current(I_{Lr}) (50V/div. 10A/div. 1usec/div.)



(b) State-plane trajectory (V_p, I_{Lr}) (50V/div. 10A/div.)



(c) V_{ds} V_{gs} of S1 (50V/div. 5V/div. 1usec/div.)

Fig. 7 Experimental waveform of proposed energy recovery circuit

V. CONCLUSION

A novel energy-recovery circuit for PDP was proposed and analyzed. The experimental results verified that the proposed circuit recovered capacitive energy efficiently without large capacitors and the soft transient of active/passive components was achieved for better efficiency, panel-voltage waveform and reduced EMI noise.

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