

## A Novel Energy Recovery Sustaining Driver with Snubber Circuits for Plasma Display Panel

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### Abstract

An energy recovery sustaining driver with zero current switching to reduce switching losses and EMI is presented in this paper. The driver with designed snubber circuits reduces ringing voltage significantly on PDP so that the voltage rating of MOSFETs can be lower as well to reduce the cost of switches.

### 1. Introduction

Due to flat panel displays with high brightness and wide view angle, the plasma display panel has been receiving more and more attention for large diagonal display application. The power consumption is a major concern for PDP in comparison with other flat displays. The energy recovery sustaining driver is the major power consumption.

The energy recovery circuits (ERCs) for PDP sustainer can be classified into four types: series ERC [1]–[3], parallel ERC [4], TERES ERC, and Multi-level voltage-fed ERC. Series and parallel ERCs are commonly used by most of PDP companies due to the high efficiency and the simple circuit structure.

In sustaining driver circuits due to large  $di/dt$  and  $dv/dt$  during switch turn-on/off transient, hard switching results in voltage and current surges on the PDP equivalent capacitor, which cause electromagnetic interface (EMI) noises, large voltage and current stress on the switches, and consequently large switch losses. However, the large  $dv/dt$  and  $di/dt$  on the MOSFETs result in large current in capacitor and large voltage in inductors. The rating of MOSFET should be selected within the maximum allowable rating.

In this paper, a novel energy recovery sustaining driver with zero current switch and snubber circuits for plasma display panel is presented in this paper. In soft switch techniques, zero voltage switching and

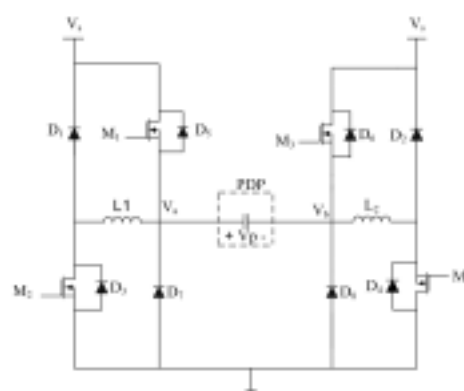


Fig. 1. The proposed ERC for ac PDP sustaining circuit.

zero current switching are often used to reduce switching losses and high voltage and current stress on the switches. Experimental results show that ringing voltage on the panel equivalent capacitance can be reduced that results in lower EMI noises.

### 2. The Proposed Energy Recovery Circuit

The proposed ERC for ac PDP is shown in Fig. 1. The series connection of  $L_1/L_2$  and  $C_p$  results in series resonance. The energy of capacitor will transfer to inductor due to resonant circuit. Then the energy in inductors has energy recovery to the source  $V_s$  to save the energy and enhance the efficiency.

The gating signals and key waveforms of the proposed circuit with snubber circuits are shown in Fig. 2, and the circuit operations of each mode shown in Fig. 3 are explained as follows:

**Mode 1 [T1]:** The panel capacitance  $C_p$  in series with the inductance  $L_2$  is connected between source  $V_s$  and the ground via the switches  $M_1$  and  $M_4$ . The

panel voltage rises like a ramp-waveform until the panel voltage reaches  $V_S$ .

**Mode 2 [T2]:** All of the switches are turned off under zero-current switch condition, then the energy stored in the inductor  $L_2$  delivers to the power source through the diodes  $D_2$  and  $D_8$  so that the energy recovery is from the inductor to source.

**Mode 3 [T3]:** The switches  $M_2$  and  $M_3$  are turned on;  $M_1$  and  $M_4$  are turned off. The panel capacitor  $C_p$  in series with the inductor  $L_1$  is charged again. The panel  $C_p$  goes down until the voltage reaches  $-V_S$ .

**Mode 4 [T4]:** All of the switches are turned off under zero-current switch condition, the energy stored in the inductor  $L_1$  delivers to the power source through the

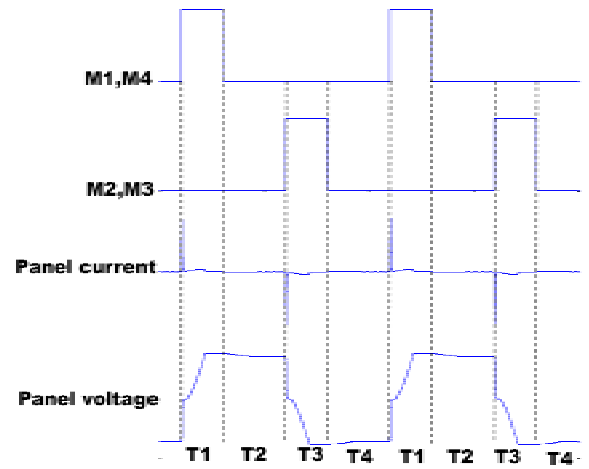


Fig. 2. The gating signals and key waveforms of the proposed circuit.

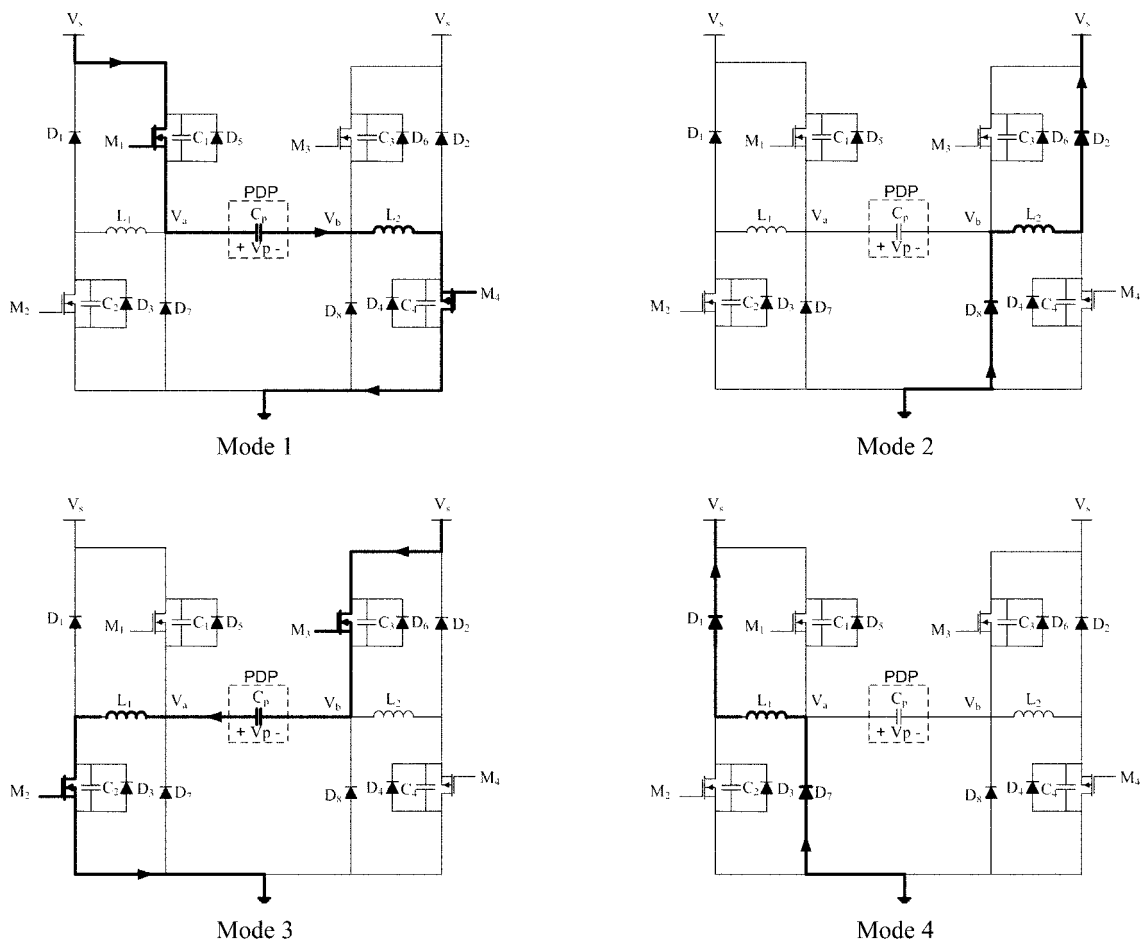


Fig. 3. The proposed ERC of each mode operation.

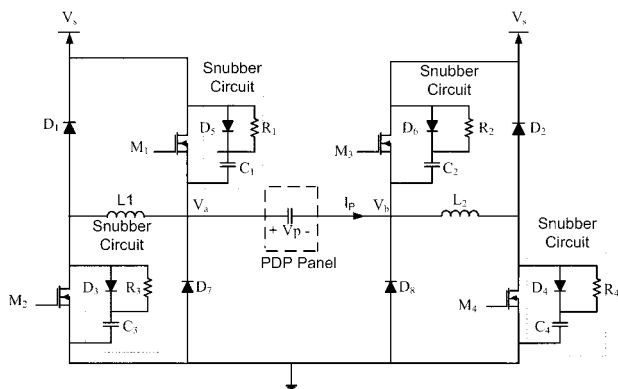


Fig. 4. The proposed ERC for ac PDP sustaining circuit with snubber circuit.

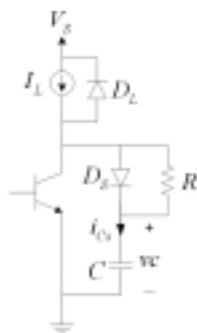


Fig. 5. The snubber circuit.

diode  $D_1$  and  $D_7$  until the energy stored in inductor  $L_1$  is completely zero.

### 3. Sustaining Driver with Snubber Circuits

When the switch is turned off, the currents through the switches do not completely shrink to zero that result in oscillation between the inductance  $L_1/L_2$  and the parasitic capacitance between the drain and source of the switch.

An ERC circuit with snubber circuits is presented in this paper as shown in Fig. 4. The circuit with resistor  $R$ , capacitor  $C$ , and diode  $D_s$  is the snubber circuit as shown in Fig. 5. The resistor  $R$  limits the discharge current of the capacitor when the switch is turned on so that  $dv/dt$  on the MOSFET M1 is limited to reduce the ringing voltage causing EMI noises and making the control signal malfunction.

TABLE I  
CIRCUIT PARAMETERS AND KEY COMPONENTS

Parameter	Value
Sustain voltage $V_s$	180 V
Switching frequency $f_s$	50 kHz
Inductance $L_1/L_2$	0.15 $\mu$ H
Switches $M_1-M_4$	NEC k2371 $\times$ 4
Diodes $D_1-D_8$	DSEP 30-06A $\times$ 8
Snubber capacitance	7.46 nF
Snubber resistance	532 $\Omega$

The value of RC are selected to make the circuit is slightly underdamped. The energy stored in the inductance  $L_1/L_2$ , which is mostly transferred to the snubber circuit to avoid coupling with the parasitic capacitor of the switch to occur high frequency oscillating voltage that results in large EMI noises. The current through snubber capacitor decreasing at turn-off transient can be derived as

$$i_{cs} = I_o \frac{t}{t_{fi}} \quad 0 < t < t_{fi} \quad (1)$$

where  $t_{fi}$  is the turn-off time of the transistor. When the  $D_s$  is conducting, the voltage of capacitor which is the same as transistor Vce voltage, can be written as

$$v_{cs} = v_{CE} = \frac{1}{C_s} \int_0^t i_{cs} dt = \frac{I_o t^2}{2C_s t_{fi}} \quad (2)$$

The capacitance can be determined as

$$C_{s1} = \frac{I_o t_{fi}}{2V_d} \quad (3)$$

Typically the resistance  $R$  can be determined by setting the reverse recovery current below 20% of  $I_L$  as

$$\frac{V_d}{R_s} = 0.2I_o \quad (4)$$

### 4. Experiment Result

A prototype of the proposed ERC with snubber, whose circuit parameters and key components are listed in Table I, is built and tested to drive an 8-inch PDP panel. The experimental waveforms without snubber circuit are shown in Fig. 6. The switches are turned off when the panel capacitor current is zero to achieve zero-current switching (ZCS) to reduce the

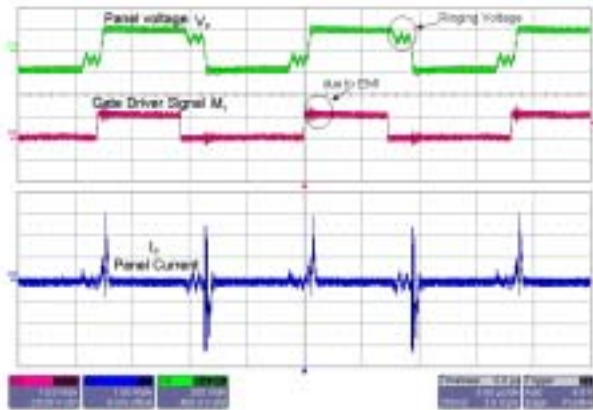


Fig. 6. The experimental waveforms of the proposed ERC for ac PDP sustaining circuit.

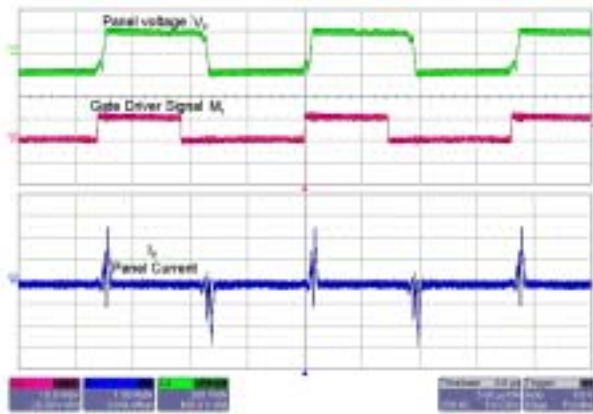


Fig. 7. The experimental waveforms of the proposed ERC with snubber circuits.

switching losses. However, the large  $di/dt$  at the turn-off transient, which causes large EMI noises, results in large ringing voltage both on panel voltage,  $V_p$  and gate driver signals. The snubber capacitor and resistance determined by (3) and (4), where  $I_O = 1.69$  A and  $t_{fi} = 1.589$   $\mu s$ , are shown in Table I. The waveforms of Fig. 7 show that experimental waveforms with snubber circuit with the same circuit parameters without snubber. It is clear that the ringing voltages in Fig. 7 is relatively small in comparison with that in Fig. 6 without snubber circuit that means the switching losses and switch stress are reduced. The peak panel capacitor current is suppressed. The overall efficiency is increased and the EMI problems are alleviated as well.

## 5. Conclusion

The proposed ERC has the ability to recovery energy from PDP to reduce energy consumption and to achieve high efficiency for PDP. The circuit structure of the proposed ERC is simpler so the circuit cost can be reduced significantly. The proposed ERC is with snubber circuit to minimize large ringing voltage across MOSFET during turn-off. The large ringing voltage is two times much greater than the normal turn-on ac PDP capacitor voltage so that the higher voltage rating of MOSFETs should be selected.

The zero-current switching reduces switching losses, EMI noises, and ringing voltage. The energy can be delivered to source from the energy stored in inductors. The ac PDP equivalent capacitor in series with inductor will increase the fall and rise time, which results in a lower capacitor current reducing the switches conduction losses. The overall efficiency would be improved. Both simulation and experimental results show the performance of the proposed ERC structure.

## 6. Acknowledgements

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## 7. References

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