

An Energy Recovery Circuit for AC Plasma Display Panel with Serially Coupled Load Capacitance-SER1

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Abstract

The switching power loss due to the panel capacitance during sustain period in AC PDP driving system can be minimized by using the energy recovery circuits. We proposed a new energy recovery circuit, SER1 (Seoul national univ. Energy Recovery circuit 1st). The experimental results of its application to a 42-inch surface discharge type AC PDP showed superior performance of SER1 in energy recovery efficiency and low distortion voltage waveform. Energy recovery efficiency of SER1 was measured up to 92.3 %, and the power dissipation during the sustain period was reduced by 15.2 W in 2000 pulse/frame compared with serial LC resonance energy recovery circuit.

Keywords : AC PDP, energy recovery circuit, SER1, efficiency.

1. Introduction

In a 42 inch AC plasma display panel, the load capacitance is about 60 nF~80 nF which would result in about 50~400 W of electrical power loss, which is very substantial, if the reactive power is not saved by using a proper energy recovery circuit. There are 2 main types of energy recovery circuit. The first type, which was suggested by Weber and Wood[2], uses series LC resonance and external capacitor. The second type, which was suggested by Sakai[3], uses parallel LC resonance.

SER1(Seoul National University Energy Recovery circuit 1st), which we reported its concept in 1998[1], uses series CLC resonance with serially coupled load capacitors.[5] In this paper, the detailed experimental results for its application to 42″ AC PDP will be discussed.

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2. The principle of SER1

Fig. 1 shows the circuit diagram of SER1 consisting of 2 load capacitors and 4 sustain driver blocks resulting in the circuit structure of CLC series resonance. Fig. 2 shows the timing diagram and the switching sequence. The resonance is initiated by the voltage level difference between X1(Y1) electrodes and X2(Y2) electrodes. The sequence of the circuit operation is described in Fig. 3. The energy recovery operation always occurs when one of the ends of the 2 capacitive loads is connected by an inductor and the other end is held to at a specific voltage. Each step in Fig.3 shows the ideal circuit model when we connect the ON state SW(Fig.2) and erase other switch elements from Fig. 1.

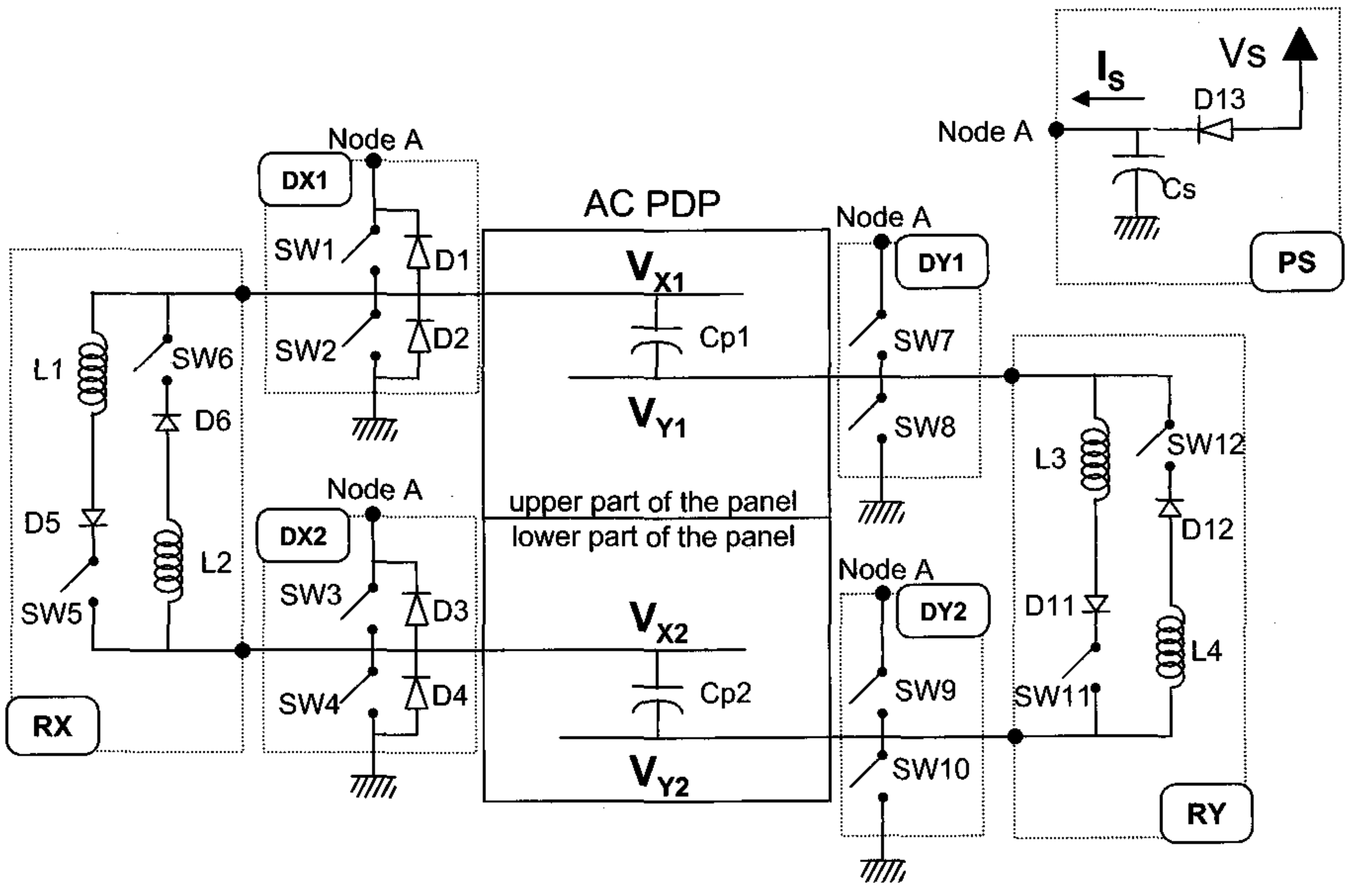

Fig. 1. Circuit diagram of SER1.

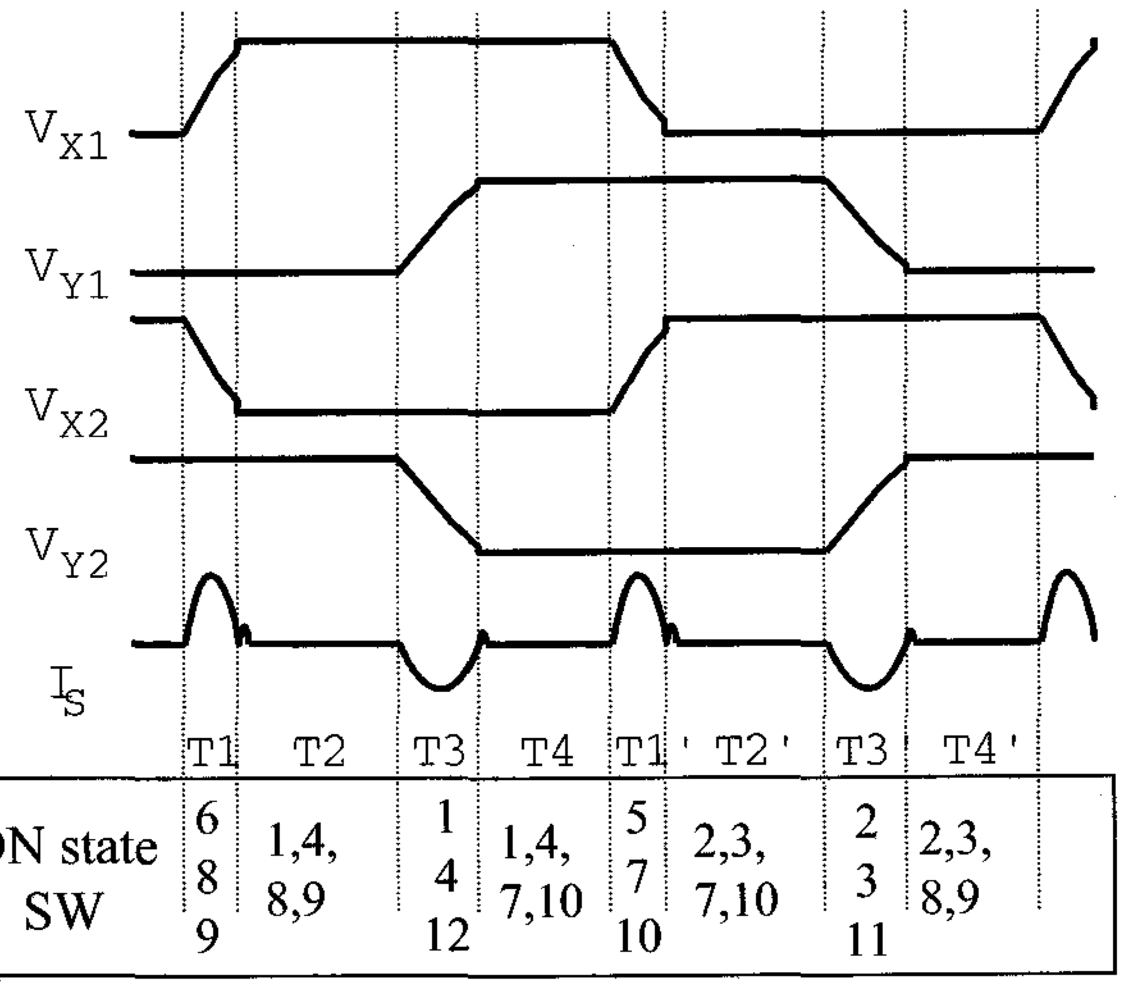

Fig. 2. Voltage and current waveforms with switching sequence in SER1.

T1', T2', T3' and T4' in Fig 2 are omitted because they are mirror states of the T1, T2, T3 and T4 each.

The sequence of operations in other energy recovery circuits is arranged in Fig. 4. The principles can be classified into serial LC resonance[2], parallel LC resonance[3] and serial LCLC resonance[6]. The third produces the same waveforms with the second even though it uses the LCLC resonance.

When the energy recovery circuits shown in Fig. 4 are used, the whole panel can be assumed as one load (C_P). As far as the parasitic series resistance in the current path is negligible compared to the reactive impedance, the rise and fall time of sustain pulses can be approximated as

$$T_{r,I,II} \cong \pi\sqrt{L_1 C_P} \tag{1}$$

Q-factor of LC resonance in each, case, is of the form,

$$Q_{I,II} = \frac{1}{R_1}\sqrt{\frac{L_1}{C_P}} \tag{2}$$

The capacitive load in the energy recovery current path of SER1 consists of two half panel capacitors ($C_P/2$)

connected in series, which yields the total capacitance of $C_P/4$. For the same rise time specification, the inductors used for the energy recovery operation can have 4 times a larger value in our case than in the other 2 types.

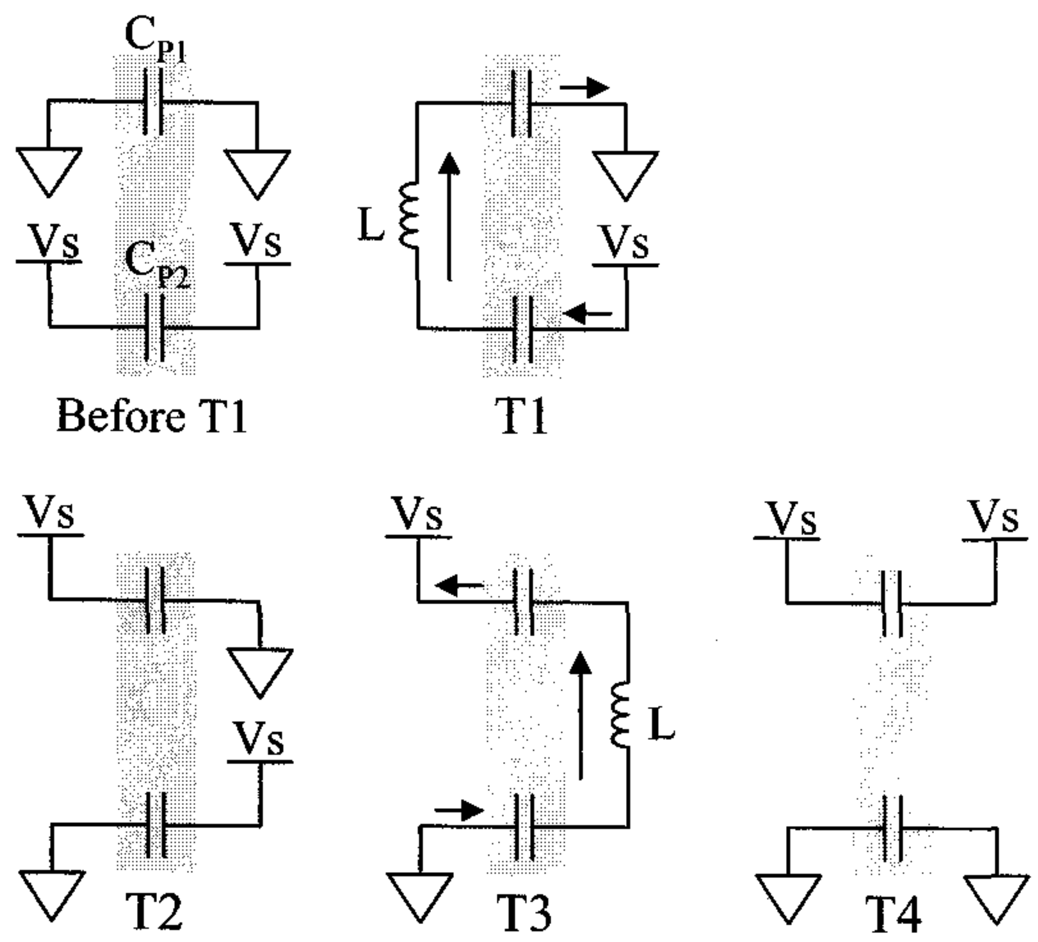

Fig. 3. Sequence of operation in SER1.

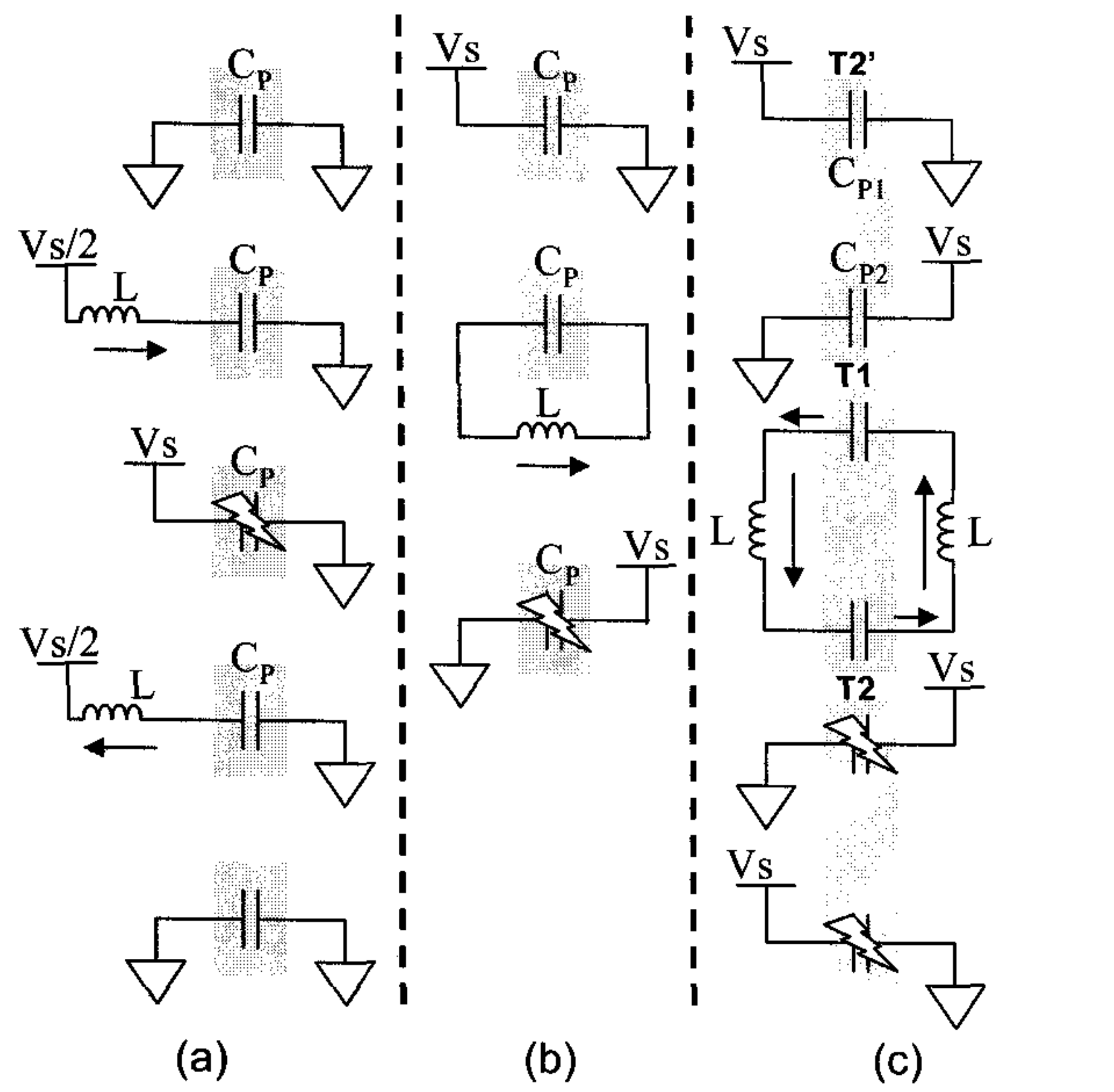

Fig. 4. Sequence of operations in various energy recovery circuits (a) Serial LC resonance (b) Parallel LC resonance (c) Serial LCLC resonance.

$$T_{r,SER} \cong \pi\sqrt{(L_2)\left(\frac{C_P}{4}\right)} = \pi\sqrt{(4L_1)\left(\frac{C_P}{4}\right)} \qquad (3)$$

The Q-factor of LC resonance in SER1 is affected by the changed inductor and capacitor values.

$$Q_{SER} = \frac{1}{R_2}\sqrt{\frac{L_2}{C_P/2}} = \frac{4}{R_2}\sqrt{\frac{L_1}{C_P}} \qquad (4)$$

From Eq.(2) and Eq.(4), it is apparent that the energy recovery efficiency of SER1 should be better as long as $R_2 < 4R_1$.

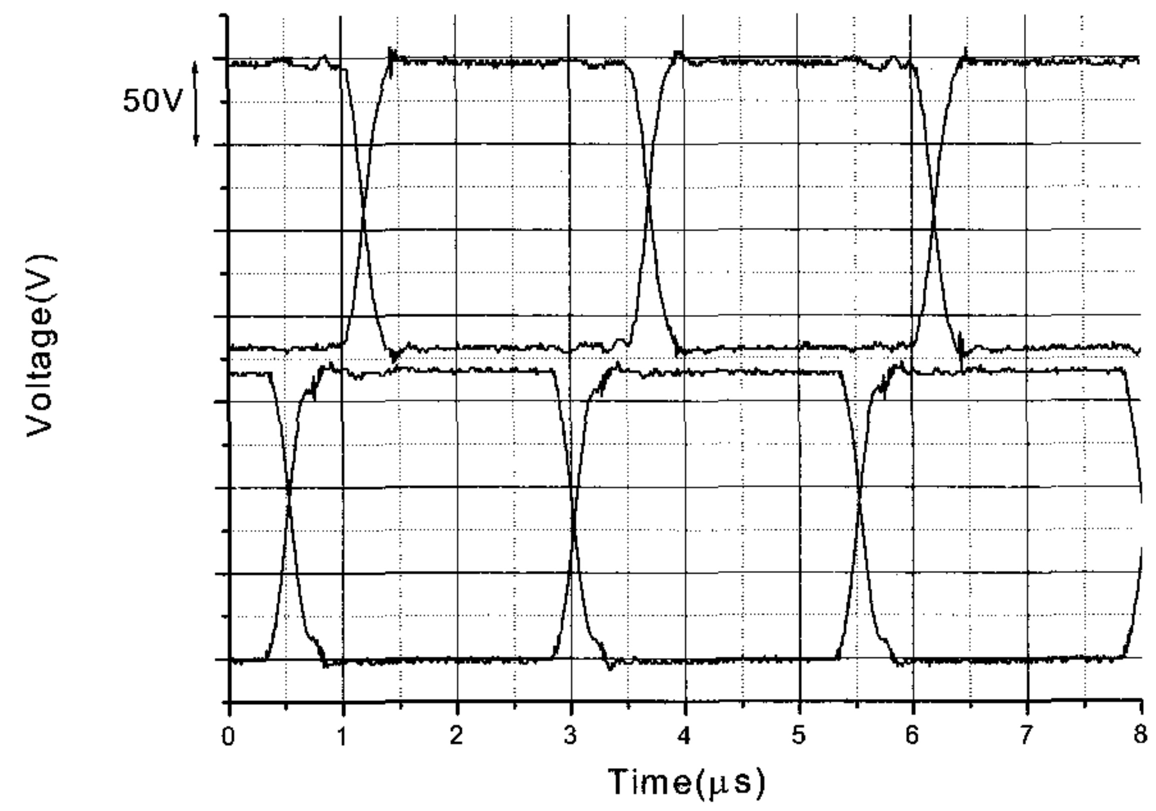

Fig. 5. Sustain pulse waveforms of SER1 in each electrode (full black display data).

Table 1. Number of components in the energy recovery part.

	Serial LC	Serial CLC (SER1)
MOSFET	8	4
Diode	24	12
Capacitor	Used	None

During the energy recovery sustain period, the voltage waveforms of the X1 and X2 are always inversed and those of Y1 and Y2, as well. If there exist some common driving periods before the beginning of the energy recovery sustain mode, there should be initialization setting the voltage level of X2 and Y2 electrodes at Vs and those of X1 and Y1 at GND before the energy recovery sustain operation. And this cannot be helped by the energy recovery circuit when we use SER1.

3. Experimental Results and Discussion

We have checked the recovery characteristics with a 42-inch AC PDP module. As SER1 needs 2 loads, the first load was selected to be the odd lines of the panel and the second to be the even lines. The rise time of sustain pulse was chosen to be about 350 ns, and the

Table 2. The energy recovery efficiency.

	Serial LC		SER1	
No recovery				
mW/period		5.32		10.01
Recovery	Cool	Steady	Cool	Steady
mW/period	1.08	1.13	0.76	0.77
Efficiency	79.7%	78.7%	92.4%	92.3%

sustain period was 5μs.

A 42-inch AC PDP module using serial LC resonance energy recovery circuit was adopted for the reference of the energy recovery efficiency. The rise time of sustain pulse in this case was chosen to also be 350 ns and the sustain period 5 μs.

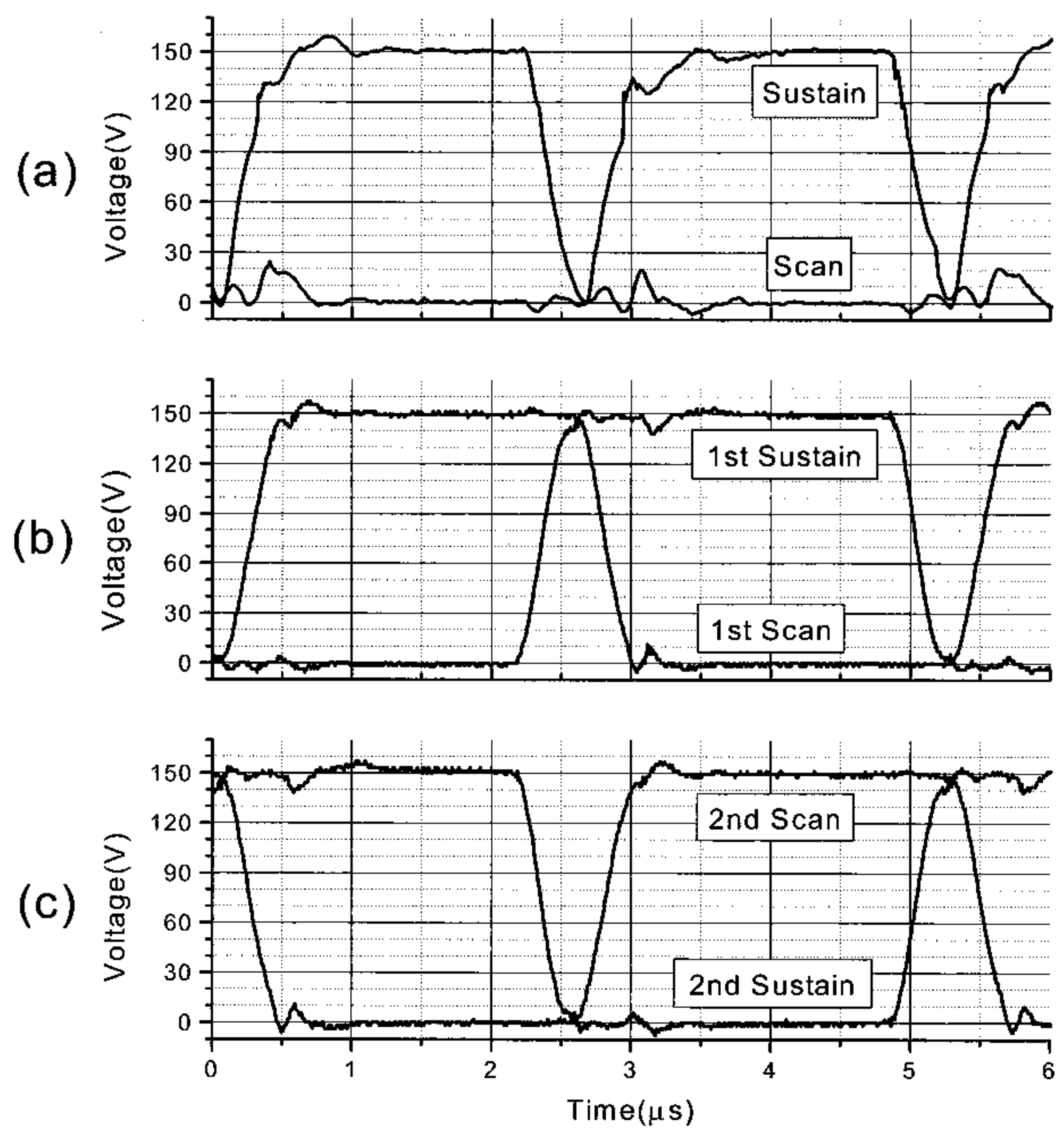

Fig. 6. Sustain pulse waveforms when full white display data are written (full sustain discharge) (a) Scan and sustain electrodes – the first type (b) 1st group scan and sustain electrodes – SER1 (c) The 2nd group scan and sustain electrodes – SER1.

As the current peak during the energy recovery operation was reduced to one half, the driving circuit board was designed to reduce the number of switches and diodes to one half of those of the first type. Table 1 shows the number of switches, diodes and capacitors in the energy recovery part.

Fig. 5 shows the measured sustain pulse waveforms of SER1. The sustain voltage was set to 165.4 V and the upper waveforms in Fig.5 correspond to the scan electrode input pulse waveforms and the lower waveforms the sustain electrode input pulse waveforms. It should be noted that the sustain discharge occurs only when the voltage levels of the scan electrodes change and does not occur when those of the sustain electrodes do. The reason is that the voltage difference between the scan electrodes and sustain electrodes is Vs or –Vs just after the energy recovery circuit of the scan electrodes (RX in Fig.1) operates and it is 0 just after the energy recovery circuit of the sustain electrodes(RY in Fig.1) operates.

Fig. 6 shows the voltage waveforms when full white data is loaded. Fig. 6 (a) shows the voltage waveforms of the circuit using the serial LC resonance energy recovery circuit, and the voltage waveforms of the circuits using SER1 are shown Figs. 6 (b) and (c). Unlike the case when full black data is loaded, significant waveform distortion due to the sustain discharge current. The voltage drop of 42.2 V in the first type case is almost 3 times higher than that of 14.7 V in SER1 case. Low voltage drop contributes to the stable sustain margin of AC PDP module. When the sustain current flows, the capacitors for stabilizing the sustain voltage in one board need to feed only one half of the sustain current.

In order to measure the energy recovery efficiency, the power consumption was measured with full black pattern. The power was measured in 2 steps due to the energy recovery efficiency degradation according to the temperature rise in the circuit boards. The measurement results in Table 2 show that the power consumption of the sustain voltage source with no energy recovery operation in the SER1 case is almost twice as high as the serial LC resonance case. This result is due to the additional capacitance between the odd lines and the even lines which is not included with the pulse waveforms of serial LC resonance case. The unique pulse waveforms of SER1 induce 4 times more power consumption with this capacitance because the voltage of odd line and even line is changed at the same time.

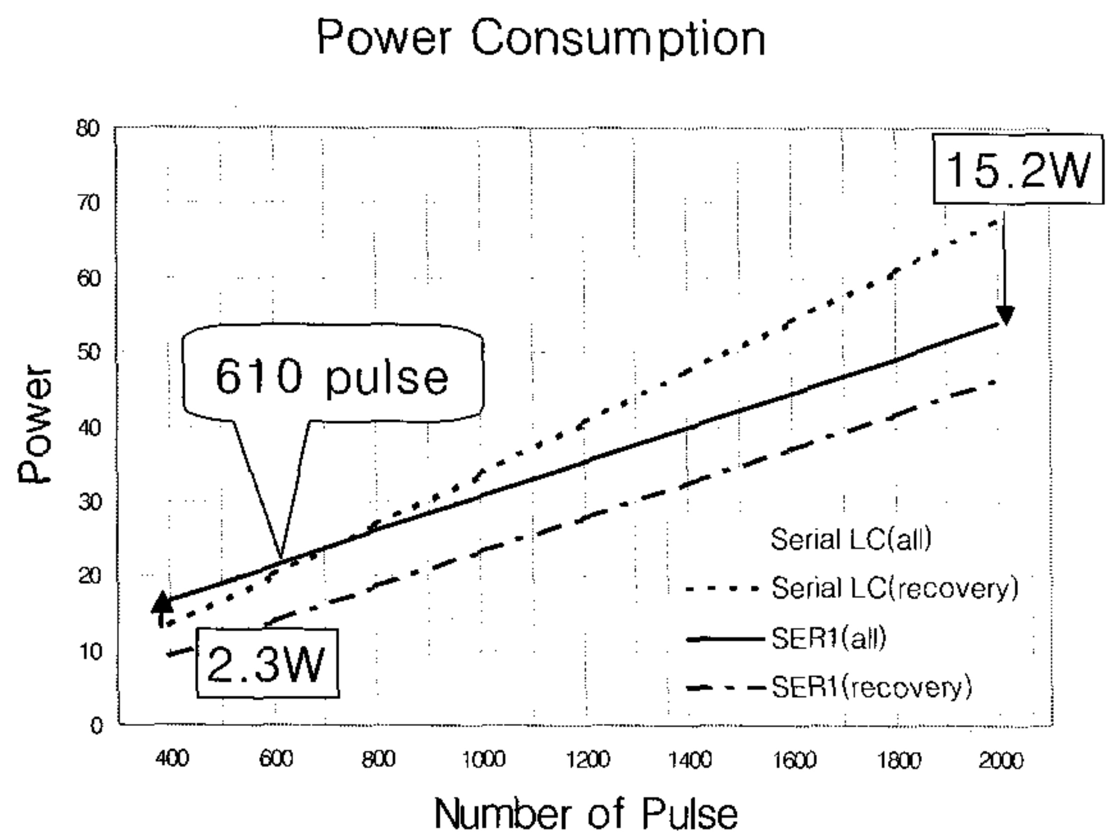

Fig. 7. Overall power consumption with respect to the number of the sustain pulse.

If the energy recovery efficiency is to be defined as the percentage of the saved energy to the energys, which should be used when the energy recovery circuit is not used for the same sustain pulse waveforms, the energy recovery efficiency of SER1 is 92.3 % when that of serial LC resonance circuit is 78.7 %.

In practical case, the overall power consumption is more important than the energy recovery efficiency itself. The power consumption was calculated and checked by the measurement results of the experiments. The result is shown in Figure 7.

As SER1 does not provide the methode to change the voltage of the electrodes when the voltage levels of the 2 blocks are the same, hard switching not using LC resonance is unavoidable without additional circuits. Reset pulses and the first sustain pulse cannot be helped by SER1.

In Fig. 7, 15.2 W decreased to 2000 pulse/frame case, and the 2.3 W increased to 400 pulse/frame case. The cross point was 610 pulse/frame. If the number of sustain pulse is higher than 610 pulse in one frame, the power consumption in the system adopting SER1 would show lower power consumption.

5. Conclusion

This paper reports the result of the application of SER1 energy recovery circuit to a 42 inch AC PDP. SER1 has been proven to show good performance in experiments. Such good performance include the full utilization of the capacitors holding sustain voltage and the serial connection of 2 capacitive loads resulting in 1/4 of original capacitance and the high energy recovery efficiency. The energy recovery efficiency was measured to be 92.3 %. Overall power consumption result in SER1 was reduction of 15.2 W reduction in 2000 pulse/frame and 2.3 W was increased in 400 pulse/frame when compared with the serial LC resonance energy recovery circuit. When the number of sustain pulse was more than 610, the power consumption of SER1 was smaller than that of serial LC resonance energy recovery circuit.

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