A Novel Integrated Nondissipative Snubber for Flyback Converter

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***Abstract*--** **This paper presents a novel integrated nondissipative snubber for flyback converter. The overall efficiency of proposed circuit is higher then that using conventional nondissipative snubber. By the use of a multi-winding transformer, the novel nondissipative snubber integrates the snubber inductor with flyback transformer in a magnetic core. The additional magnetic core, using in conventional nondissipative snubber, is not need for the proposed circuit.**

To verify the performance of proposed topology, an experimental prototype is built to demonstrate the performance of the proposed integrated nondissipative snubber. The experimental results show the advantages of the proposed circuit.

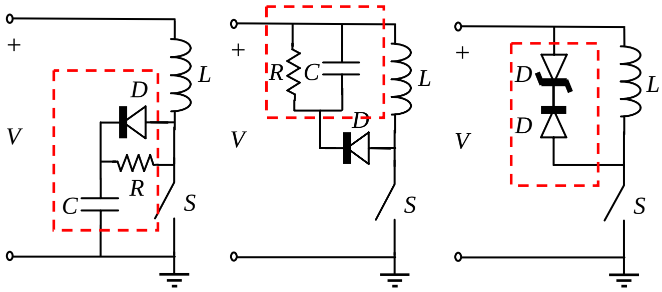
I. INTRODUCTION

A turn off snubber is frequently used in switching power applications to limit the rate of rise voltage across the switching device at turn off. In this chapter, the conventional dissipative snubber and nondissipative snubber circuits are reviewed. It involves conventional RCD [1], regeneration RCD [2], TVS [3]-[4] passive and active nondissipative snubber. A novel nondissipative snubber integrates with flyback converter is proposed. The mathematics analysis of proposed circuit is derived along with five operating states. The simulation and the experimental results have shown the advantage of the proposed circuit. Comparison among these snubber circuits is present.

Usually, a snubber capacitor is used in turn off snubber circuit, the power in the snubber circuit to be dissipated or transferred. This dissipated or transferred power can be expressed as

$$P_c = \frac{1}{2} C V_I^2 f_s \qquad (1)$$

Where V_I is the DC bus voltage and f_s is the switching frequency. To obtain a smaller volume and achieve fast regulation, the switching frequency of modern power supplies is normally higher than 50 kHz. Therefore the P_c is increased and the overall efficiency is decreased. Fig. 1 shows the conventional snubber circuits. In Fig. 1(a), an RCD snubber is paralleled with the power switch. The power storage in the capacitor C_s during turn-off period must be dissipated by the resistor R_s while S is turned on. The disadvantage is increasing the turn-on current of switch. The improved scheme is shown in Fig. 1(b). It can be observed that the capacitor energy is discharged by the parallel resistor directly, and it will not cause additional current on the power switch while the switch is turned on. For flyback converter, a transient voltage suppressor (TVS) shown in Fig. 1(c) is widely employed in low power applications. D_s and D_z are used to reduce the leading-edge voltage spike and ringing caused by transformer leakage inductance to a safe value. However, these dissipative snubbers can not meet the high efficiency desired for modern power supply.



(a) (b) (c)

Fig. 1 Conventional dissipative turn off snubber;
(a) RCD snubber parallel with the power switch.
(b) RCD snubber parallel with the primary winding.
(c) TVS snubber parallel with the primary winding.

II. REGENERATIVE AND NONDISSIPATIVE SNUBBERS

To improve the overall efficiency of power converter, several regenerative and nondissipative snubber circuits were proposed. They are reviewed as follows:

(A). RCD regenerative snubber

Fig. 2(a) shows a RCD regenerative snubber with additional ferrite transformer without active device. This method can be passively recovered more than 70% of P_c into the DC bus. However, it still dissipates part of P_c on the snubber resistor R_s.

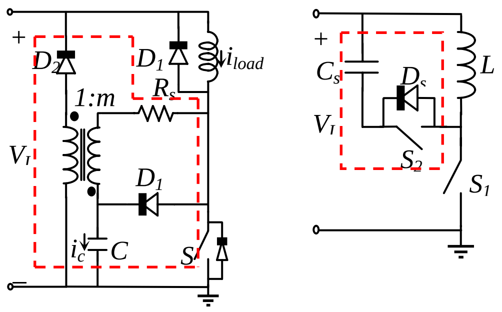
(B). Active clamp snubber

An alternated scheme of regenerative snubber shown as Fig. 2(b) is active clamp snubber [5]-[9]. The incorporation of the active clamp circuit into basic flyback topology not only regenerates the energy stored in snubber capacitor; it can also achieve zero voltage switching (ZVS) for the power switches [10]-[11]. Of cause, the additional active switch and complicated controller are needed in this topology.

(C). Passive nondissipative snubber

A simple and cost advantageous regenerative snubber for flyback converter shown in Fig. 3 is a passive nondissipative snubber [12]-[16]. The nondissipative snubber can decrease substantially the turn off switching loss and regenerated the energy stored in snubber capacitor to DC bus or in the magnetizing inductor L_m of the flyback transformer.

III. PROPOSED INTEGRATED NONDISSIPATIVE SNUBBER



(a) (b)

Fig. 2 (a) A regenerative RCD snubber with a ferrite transformer. (b) basic active-clamp snubber circuit.

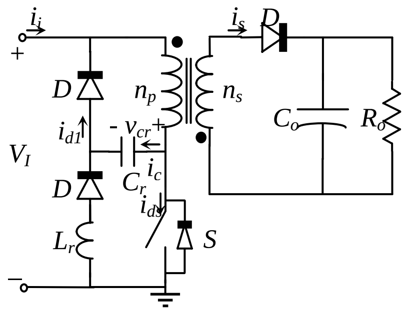


Fig.3 Nondissipative snubber with a flyback converter.

From the concept of multiple-winding transformer, a novel nondissipative snubber by multiple-winding transformer is proposed. Multiple-winding transformer or couple inductors are employed wildly such as magnetizing energy reset, multiple output power supply [17], reduction the cross-regulation of output voltage[18] and ripple suppression [19]-[22].

In this paper, a novel nondissipative snubber integrated the snubber circuit with the flyback circuit by the addition of a third winding in the transformer. It can be observed in Fig. 4, the energy stored in snubber capacitor will recovery to DC bus and the magnetizing inductor L_m of the flyback transformer. The mathematics analysis and the results of simulation and experiment are presented in next section.

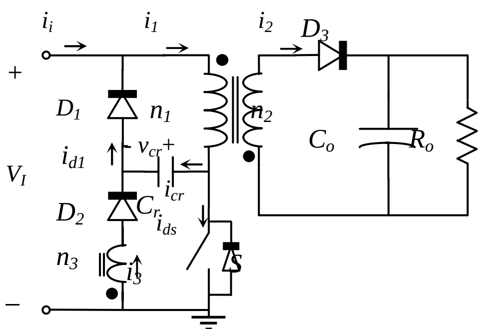


Fig. 4 The proposed nondissipative snubber integrated with flyback converter.

Analysis of proposed integrated nondissipative snubber

There are five operating states in the steady state of the proposed integrated nondissipative with a flyback converter. Table 1 lists the device conduction mode of the proposed circuit. The duration of the operating states is present in Fig. 5, showing circuit waveforms over one switching period. The operations of proposed circuit can be observed and analyzed. Table 2 lists the symbols of the parameters of proposed circuit. Each operating state is as analyzed as follows:

Table 1. Device conduction mode.

	State				
D	**1**	**2**	**3**	**4**	**5**
S	ON	ON	OFF	OFF	OFF
D_1	OFF	OFF	ON	OFF	OFF
D_2	ON	OFF	OFF	OFF	ON
D_3	OFF	OFF	ON	ON	OFF

Table 2. The symbols of the proposed circuit.

L_m	magnetizing inductance on primary side
L_2	the equivalent inductance on secondary side
L_3	the equivalent inductance on the third winding
L_{m31}	mutual inductance between third and primary side converted to third side.
L_{m32}	mutual inductance between third and secondary side converted to third side.
L_{l12}	leakage inductance between primary and secondary side converted to pri mary side.
L_{l31}	leakage inductance between third and primary side converted to third side.
L_{l32}	leakage inductance between third and secondary side convert to third side.
n_{12}	turns ratio of n_1/n_2
n_{31}	turns ratio of n_3/n_1

(A). State 1 (t_0-t_1)

As shown in Fig. 5 and Fig. 6(a), S and D_2 are turned on in this operating state, the voltage of capacitor v_{cr} is discharged to the magnetizing inductor L_m and DC bus through the third winding n_3. From Fig. 6(a), the capacitor can be expressed as:

$$v_{Cr} + L_{p2} C_r \frac{d^2 v_{Cr}}{dt^2} = k_{31} V_i \qquad (2)$$

where

$$k_{31} = \frac{L_{m31} n_{31} V_i}{L_{m31} + n_{31}^2 L_{l13}} \qquad (3)$$

$$L_{p2} = L_{l31} + L_{m31} // n_{31}^2 L_{l31} \qquad (4)$$

$$i_{Cr} = C_r \frac{dv_{Cr}}{dt} \qquad (5)$$

let $$v_x = v_{Cr} - L_{l31} \frac{di_3}{dt} \qquad (6)$$

$$\frac{di_1}{dt} = \frac{V_i}{L_{l31}} + \frac{v_x}{n_{31} L_{l31}} \qquad (7)$$

$$i_1 = \frac{V_i}{L_{l31}}(t - t_0) - \frac{1}{n_{31} L_{l31}} \int_{t_0}^{t} v_{Cr} dt + \frac{1}{n_{31}} i_{Cr} = i_i \qquad (8)$$

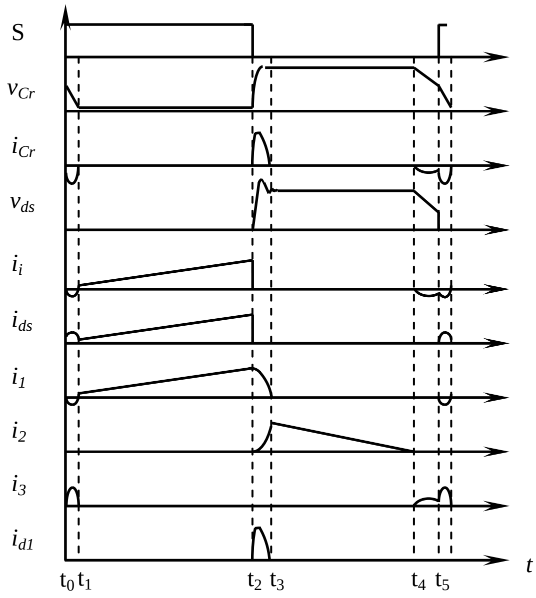


Fig. 5 The circuit waveforms of the proposed nondissipative snubber integrated in flyback converter.

$$i_2 = 0, \quad i_3 = -i_{Cr} \tag{9}$$

$$v_{Co} = -\frac{1}{R_o C_o}\frac{dv_{Co}}{dt} \tag{10}$$

(B). State 2 (t_1-t_2)

This operating state is the same as the turn on state of a typicle flyback circuit. Thus, only the switch S is turned on in this state. The magnetizing inductor L_m is charged by the DC bus, and the input current can be expressed as follows:

$$i_i = i_1 = \frac{v_i}{(L_{l12} + L_m)}(t - t_1) + i_1(t_1) \tag{11}$$

$$i_2 = 0, \quad i_3 = 0 \tag{12}$$

(C). State 3 (t_2-t_3)

In this state, the switch S is turned off firstly, a part of the energy stored in leakage inductor L_{l1} is absorbed by the capacitor C_r. Thus the switch voltage slop and overshoot are reduced, and resulting in lower turn-off loss. Then, the diode D_3 is conducted to charge the output capacitor. In this state, the relative circuit parameters can be expressed as follows:

$$v_{Cr} + (L_{l12} + L_m)C_r \frac{d^2 v_{Cr}}{dt^2} = 0 \tag{13}$$

$$i_i = 0\ , \tag{14}$$

$$i_1 = i_{cr} = C_r \frac{dv_{cr}}{dt} \tag{15}$$

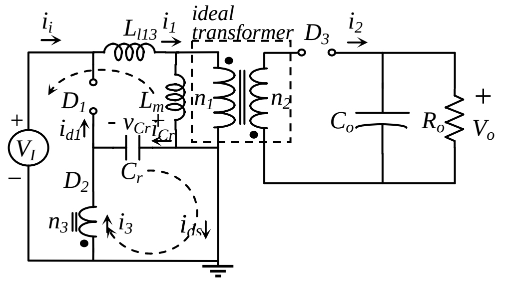
$$i_2 = n_{12}(i_{cr}(t_2) - i_{cr}(t)) \tag{16}$$

$$v_{Co} = -\frac{1}{R_o C_o}\frac{dv_{Co}}{dt} \tag{17}$$

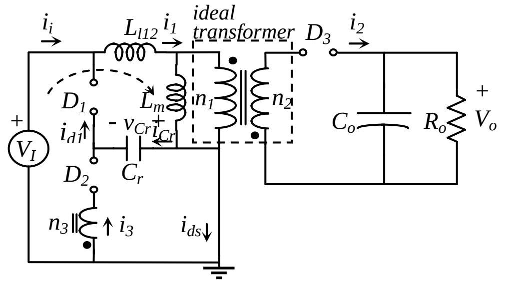
$$i_i = 0\,, i_1 = 0\,, i_{Cr} = 0\,, i_3 = 0 \tag{18}$$

(D) State 4 (t_3-t_4)

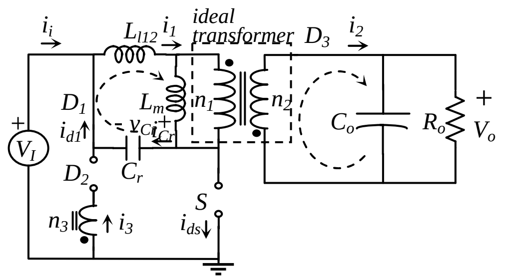
The energy stored in magnetizing inductor L_m is



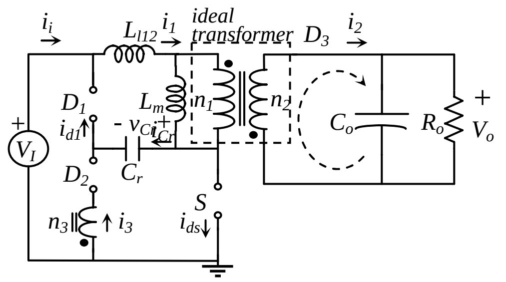
(a) State1: t_0-t_1



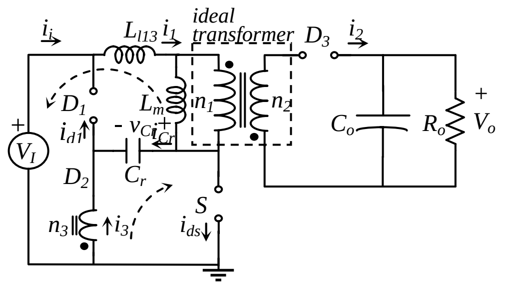
(b) State 2 : t_1-t_2



(c) State 3: t_2-t_3



(d) State 4: t_3-t_4



(e)State 5: t_4-t_5

Fig. 6 Operating states of the proposed circuit.

discharged through the secondary side, the capacitor C_o and the load R_o absorb the energy from L_m. It results in

$$i_2 \cong -\frac{V_o}{L_2} + i_2(t_3) \tag{19}$$

$$v_{Co} = -\frac{1}{RC}\frac{dv_{Co}}{dt} \qquad (20)$$

while the energy in L_m is decreasing to zero, D_3 is turned on and D_2 is conducted.

(E) State 5 (t_4-t_5)

The capacitor voltage v_{cr} is dicharged through D_3, winding n_3 and winding n_1 to the DC bus. The equations can derived as follows:

$$i_{Cr} = C_r \frac{dv_{Cr}}{dt} \qquad (21)$$

$$\frac{di_{Cr}}{dt} = C_r \frac{d^2 v_{Cr}}{dt^2} \qquad (22)$$

$$v_i = L_{l12}\frac{di_{Cr}}{dt} + n_{12}v_o + v_{Cr} + L_{l32}\frac{di_{Cr}}{dt} + n_{32}v_o \qquad (23)$$

$$v_i = L_{l12}C_r \frac{d^2 v_{Cr}}{dt^2} + n_{12}v_o + v_{Cr} + L_{l32}C_r \frac{d^2 v_{Cr}}{dt^2} + n_{32}v_o \qquad (24)$$

$$v_i = \left(L_{l12}C_r + L_{l32}C_r\right)\frac{d^2 v_{Cr}}{dt^2} + \left(n_{12} + n_{32}\right)v_o + v_{Cr} \qquad (25)$$

$$\frac{d^2 v_{Cr}}{dt^2} + \frac{v_{Cr}}{L_{l12}C_r + L_{l32}C_r} = \frac{v_i - \left(n_{12} + n_{32}\right)v_o}{L_{l12}C_r + L_{l32}C_r} \qquad (26)$$

It can be observed in Fig. 6(e), the capacitor energy regenerated to DC bus and flyback transformer has not through the diode D_1. Thus, more power loss of proposed nondissipative snubber is reduced than that in conventional nondissipative snubber.

IV. SIMULATION AND EXPERIMENTAL RESULTS

The IsSpice circuit simulation program was used to evaluated performance of the proposed circuit evaluation. In addition, an experimental prototype has built to show the performance of the proposed integrated nondissipative snubber. The specifications and parameters for simulation and experimental prototype are listed in Table 3.

It can be observed in Fig. 7, the capacitor current i_{cr} is positive while S is turned off, and it become negative while D_3 is turned off and S is turned on. During one switching period, the average value of the capacitor current i_{cr} is zero. The energy stored in snubber capacitor is regenerated to DC bus and to the flyback transformer. Fig. 7(a) shows the simulation results, it is similar to that in Fig. 7(b), which are the experimental results.

Fig. 8 (a) and (b) shows the switch voltage v_{ds} and current i_{ds} by simulating and experimenting, respectively. It can be observed that, there is a current spike of i_{ds} while S is turned on. It is results in the resonant current of LC snubber. As shown in Fig. 9 (a) and (b), the input current exits negative duration cause by energy feedback to DC bus and the flyback transformer.

To make a comparison of power efficiency among conventional nondissipative snubber, RCD snubber and proposed nondissipative snubber, the prototypes of flyback circuit with conventional nondissipative and RCD snubber had built and tested. The converter circuit quantities are tabulated in Table 4 and Table 5. The experimental voltage and current waveforms of C_r and S are shown in Fig. 10 and Fig. 11, respectively. As shown in Fig. 10, the capacitor voltage v_{cr} can be discharged to a negative value, it is good for reducing turn-off loss of power switch. Because the snubber inductor L_r is used by additional magnetic core, it allows obtaining a larger value of inductance and reducing the peak discharge current of C_r. However, the diode D_1 and L_r still dissipate a part of the energy storaged in capacitor C_r. Fig. 12 shows the experimental waveforms of v_{cs} and v_{ds} of the prototype with RCD snubber.

The comparison of power efficiency measured in the prototypes is shown in Fig. 13. The efficiency of proposed topology is higher than that with conventional nondissipative snubber and RCD snubber. The overall efficiency of proposed topology is 83% at full load in DCM operation. It is effective for improving the efficiency of flyback circuit in DCM operation.

Table 3 The specifications and parameters of prototype with proposed topology.

V_I	V_o	n_1	n_2	L_m	L_r	C_r	C_O	R_o
V		Turns		uH		nF	uF	Ω
150	15	60	10	340	50	4.7	220	3.75

Table 4 The specifications and parameters of prototype with conventional nondissipative snubber.

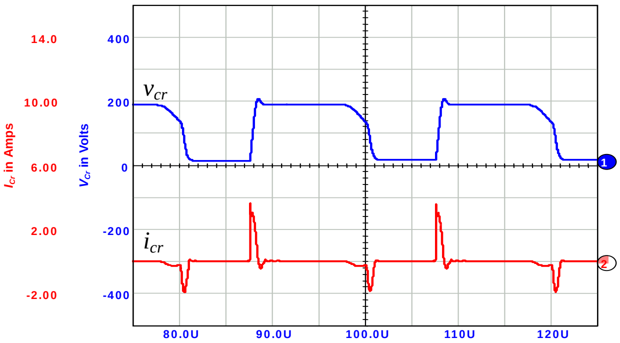
V_I	V_o	n_1	n_2	L_m	C_s	C_O	R_s	R_o
V		Turns		uH	nF	uF	Ω	
150	15	60	10	340	2.2	220	6.8k	3.75

Table 5 The specifications and parameters of prototype with RCD snubber.

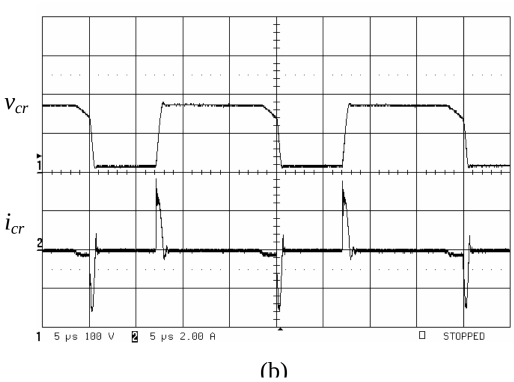
V_I	V_o	n_1	n_2	n_3	L_m	L_{l12}	L_{l13}	C_r	C_O	R_o
V		Turns			uH			nF	uF	Ω
150	15	60	10	30	340	10	10	9.4	220	3.75

V. CONCLUSION

In this paper, a novel integrated nondissipative snubber is presented to improve the efficiency of flyback converter. The analysis of proposed topology is presented. To verify the performance of proposed topology, an experimental prototype has built to show the performance of the proposed integrated nondissipative snubber. The simulation and the experimental results have shown the advantage of the proposed circuit.

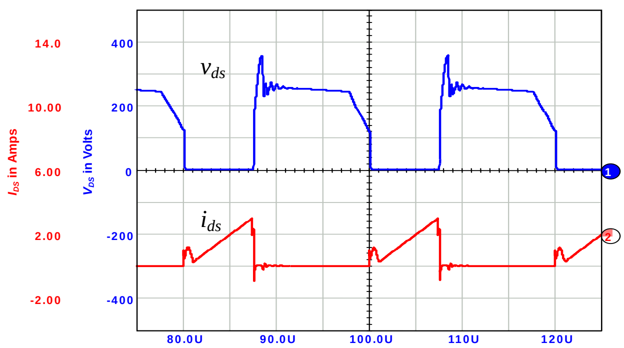


(a)

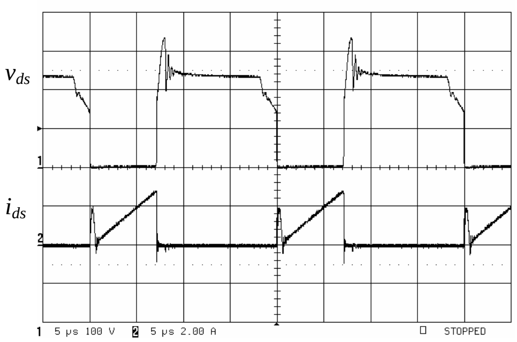


(b)

Fig. 7 The voltage and current of the snubber capacitor. (a) Simulation results (b) Experimental results. (100V/div.; 2A/div.; 5μs/div.)

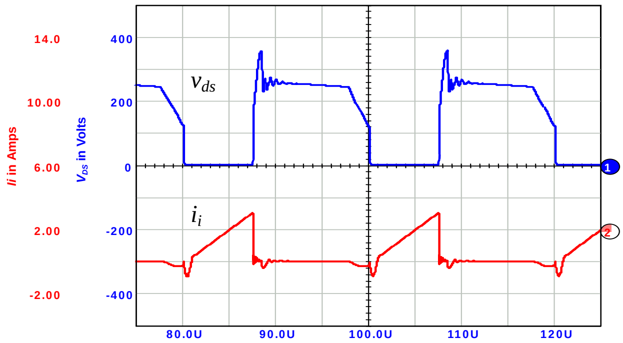


(a)

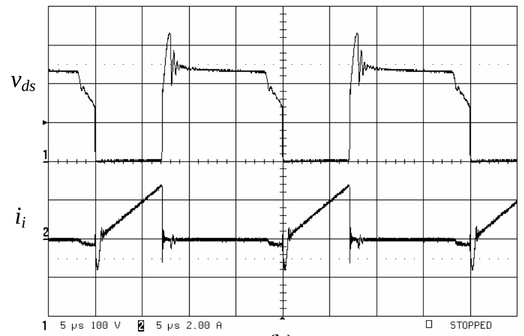


(b)

Fig. 8 The switch voltage v_{ds} and current i_{ds}. (100V/div.; 2A/div.; 5μs/div.) (a) Simulation results. (b) Experimental results.



(a)



(b)

Fig. 9 The switch voltage v_{ds} and input current i_i. (100V/div.; 2A/div.; 5μs/div.) (a) Simulation results. (b) Experimental results.

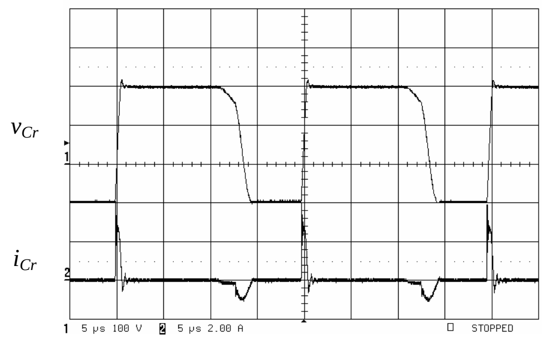


Fig. 10 The capacitor voltage v_{Cr} and current i_{Cr} with conventional non-dissipative snubber. (100V/div; 2A/div; 5μs/div.)

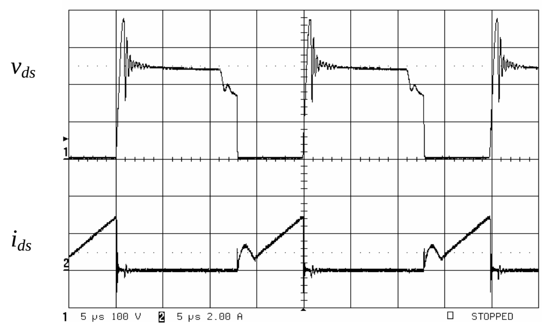


Fig. 11 The voltage v_{ds} and current i_{ids} with conventional non-dissipative snubber.(100V/div.; 2A/div.; 5μs/div.)

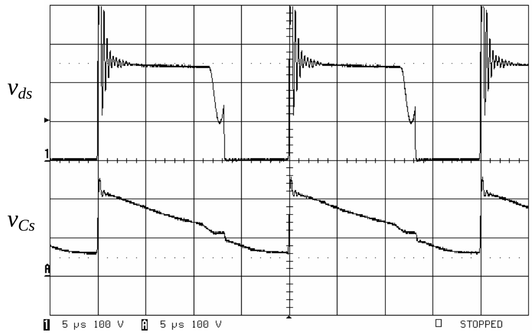


Fig. 12 The voltage v_{ds} and current v_{Cs} with conventional RCD snubber. (100V/div.; 5μs/div.)

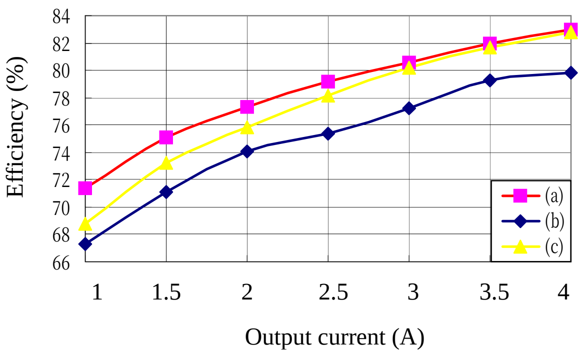


Fig. 13 The experimental efficiency measured in the prototype with (a) proposed integrated non-dissipative snubber, (b) conventional RCD snubber and (c) conventional non-dissipative snubber.

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