

Quasi-Resonant Flyback Converter with New Valley Voltage Detection Mechanism

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Abstract—In quasi-resonant (QR) controller, sensing the current of the power switch and using a delay time are commonly used to achieve valley-voltage-switching. However, the accuracy of valley-voltage switching instant in both methods are affected by the components variations during manufacturing. A primary-side QR-control IC for flyback converter with a novel valley detector is proposed to solve this problem. By sensing the auxiliary winding voltage, the controller estimates the quarter of the resonant period. And the time which the voltage across the power switch decreasing to valley is estimated accurately. Additionally, the primary-side control is adopted to reduce the size and cost of circuit. Finally, this controller is fabricated with TSMC 0.25 μm CMOS high voltage mixed-signal general purpose process, and applied to an input voltage of 90-264 Vrms, output voltage of 12 V, and output power of 30 W flyback converter to verify the feasibility of proposed control.

I. INTRODUCTION

In general, the flyback converter is widely used for adapters due to its simple structure and electrical isolation. Conventionally, an optocoupler in the secondary-side provides the isolation and feedbacks the output information [1]-[2]. Comparing with secondary-side regulation, primary-side control strategy can achieve lower component counts, lower cost, and lower power consumption on feedback circuits.[3]-[4]. The output voltage can be sampled through the auxiliary winding during the conduction period of secondary-side diode. In order to improve efficiency further, the quasi-resonant (QR) control which makes the power switch turn on at the valley voltage and reduces the turn-on switching loss is presented in [5]. Generally, most of the QR controllers on the market use the delay time to achieve the valley-voltage-switching (VVS) [6]. Since the resonant frequency is varied with the different power switch and transformer, the fixed delay time does not allow the power switch to turn on at the valley voltage precisely. A method to forecast the resonant valley voltage by using the resonant characteristic between the primary-side inductor and output capacitor of power switch is proposed. The power switch of the flyback converter can be turned on at the valley voltage under different resonant frequency conditions by proposed method.

II. ANALYSIS OF THE PROPOSED CONTROL

Fig. 1 illustrates the concept of the proposed QR control, and the analysis divided into four modes is discussed as follows. At mode 1 ($t_0 \sim t_1$), the switch S_1 is turned on. The magnetizing inductor L_m receives energy from input source. At mode 2 ($t_1 \sim t_2$), the output capacitor of the switch is charged until the voltage across the switch v_{DS} equals to $v_{in} + nV_o$. The magnetizing inductor transfers energy to the secondary-side. At mode 3 ($t_2 \sim t_3$), the magnetizing inductor L_m resonates with the output capacitor of the switch C_{oss} at $t = t_2$ which is called the knee-point. The output capacitor of the switch C_{oss} discharges to the magnetizing inductor L_m . The voltage across the switch v_{DS} decreases and the auxiliary winding v_{aux} drops to zero at $t = t_3$. At mode 4 ($t_3 \sim t_4$), the magnetizing inductor L_m delivers the energy to the output capacitor of the switch C_{oss} , and the voltage across the switch v_{DS} decreases from v_{in} to the resonant valley voltage. Then, the switch is turned on at $t = t_4$.

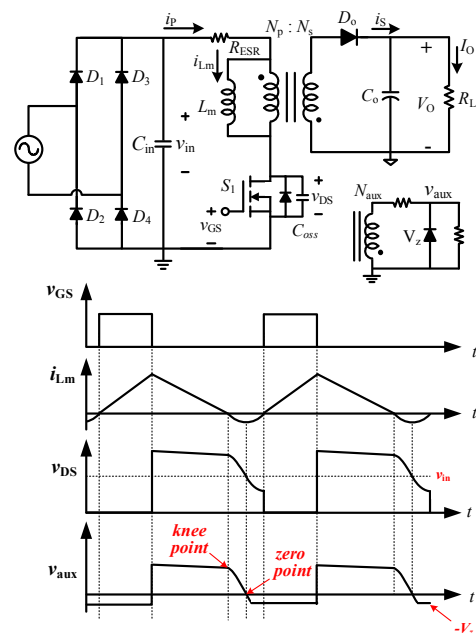


Figure 1. Concept of proposed QR control

Since the resonant period T_r is fixed, the timing t_4 can be calculated by using the Eq. (1)

$$t_4 - t_3 = t_3 - t_2 = T_r / 4 \quad (1)$$

The proposed controller detects the valley voltage by using the resonant characteristic between the magnetizing inductor L_m and the output capacitor of the switch C_{oss} . The voltage across the switch v_{DS} oscillates and the amplitude of v_{DS} attenuates gradually because of the equivalent series resistance R_{ESR} . Fig. 2 shows the equivalent resonant circuit.

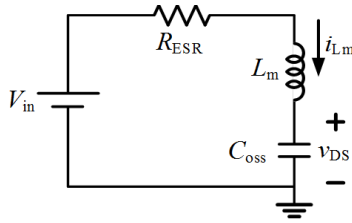


Figure 2. Equivalent resonant circuit

The initial current of L_m is zero and the initial voltage of C_{oss} is

$$v_{DS}(t_0) = V_{in} + n \cdot V_O \quad (2)$$

According to KVL, the equation of equivalent resonant circuit can be expressed as

$$R_{ESR} \cdot i_{Lm}(t) + L_m \frac{di_{Lm}(t)}{dt} + \frac{1}{C_{oss}} \int_{t_0}^t i(t) dt = V_{in} \quad (3)$$

From Eq. (3) and the initial condition of L_m and C_{oss} , the voltage on C_{oss} can be derived as

$$v_{DS}(t) = V_{in} + n \cdot V_O \cdot e^{-\alpha t} \cdot \cos(2\pi f_r \cdot t) \quad (4)$$

Eq. (4) illustrates that the minimum v_{DS} occurs at the half of resonant period $T_r/2$. Since the resonant frequency f_r only depends on L_m and C_{oss} . The timing of valley voltage can be found by doubling the quarter of resonant period $T_r/4$.

Fig. 3 shows the system diagram of the primary-side controlled flyback converter with the proposed valley detector. The control circuit is composed of valley detector, V_O sample, PWM circuit and oscillator, compensator, and HV buffer.

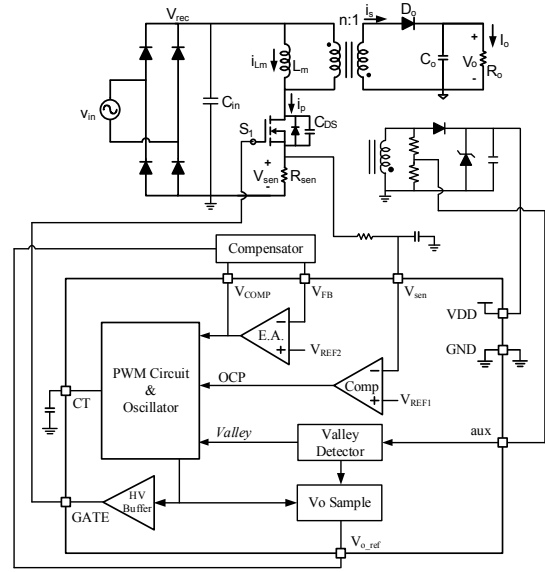


Figure 3. Flyback converter with the proposed controller

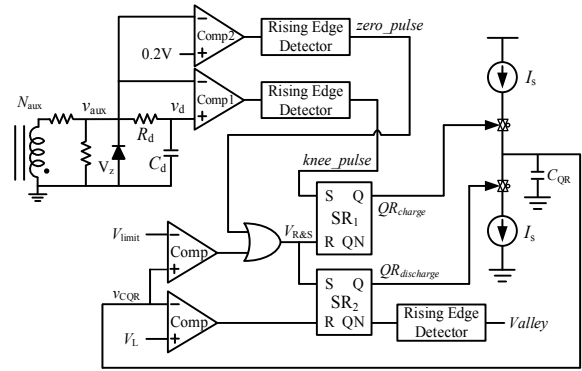


Figure 4. Schematic of valley detector

Fig. 4 and Fig. 5 show the circuit diagram and the key waveforms of valley detector, respectively. To measure the quarter of resonant period $T_r/4$, the knee-point and zero-point detectors are used. The knee-point which is the end point of secondary-side diode conduction period can be found by comparing v_{aux} with v_d . Due to the effect of RC delay circuit, v_d decreases slower than v_{aux} . During $t_0 \sim t_1$, when v_{delay} is higher than v_{aux} , the pulse signal *knee_pulse* sets SR₁, and the upper constant current I_s starts to charge the capacitor C_{QR} . The auxiliary winding voltage v_{aux} drops to 0.2 V at $t = t_1$. During $t_1 \sim t_2$, C_{QR} is discharged by the lower constant current source I_s , since the *zero_pulse* signal resets the SR₁ and sets the SR₂. At $t = t_2$, the voltage across C_{QR} drops to V_L and the signal *Valley* is sent to PWM circuit. Because the charging current is the same as the discharging current, the charging time and the discharging time of C_{QR} are also the same. As shown in Fig. 4, the QR_{charge} and $QR_{discharge}$ can represent the quarter of resonant period $T_r/4$, and the half of resonant period $T_r/2$ can be expressed as

$$T_r / 2 = 2 \cdot (T_r / 4) = \frac{2 \cdot C_{QR} \cdot (V_{CQR} - V_L)}{I_s} \quad (2)$$

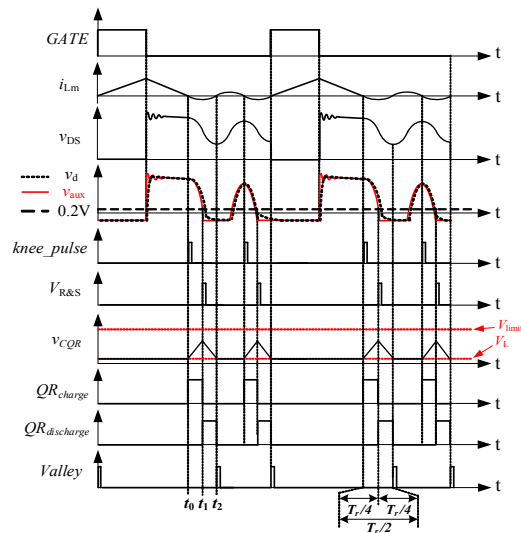


Figure 5. Waveforms of valley detector

III. EXPERIMENTAL RESULTS

The system specifications are listed in Table I. The experimental waveforms of valley detector under various load conditions are shown in Fig. 6 (a), (b). As shown, the *Valley* signals are triggered when v_{DS} resonates to the valley voltage.

TABLE I. SPECIFICATIONS OF FLYBACK CONVERTER WITH PROPOSED CONTROLLER

Specifications	Value	Unit
RMS Input AC voltage (v_{ac})	90 ~ 264	V _{rms}
Output voltage (V_o)	12	V
Output power (P_o)	30	W

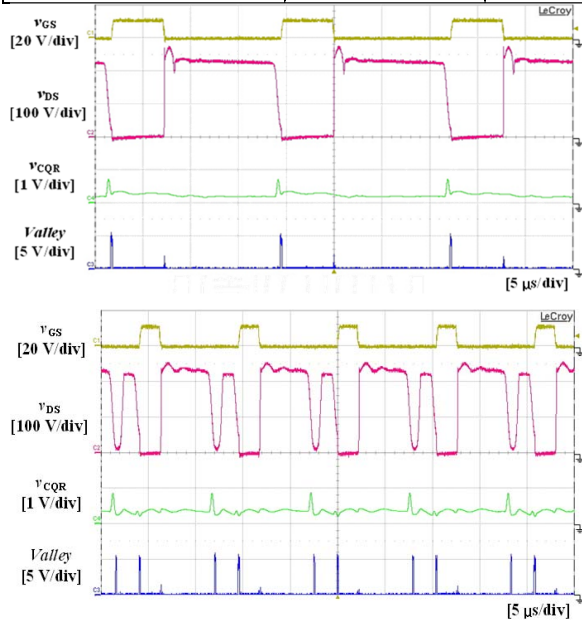


Figure 6. Waveforms of valley detector under various load conditions at $v_{ac} = 110$ V_{rms} (a) 100% load (b) 25% load

The measured efficiency curve under various load conditions at $v_{ac}=110$ V_{rms} is shown in Fig. 7. Since the switching loss dominates the power loss in light load condition, the efficiency decreases with the decreasing load. The maximum efficiency is about 89.6% when the output power is 30 W.

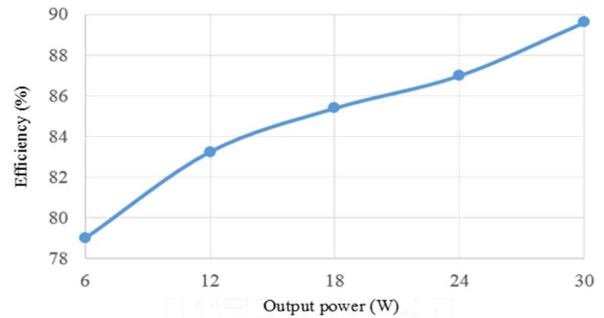


Figure 7. Efficiency curve under various load conditions at $v_{ac} = 110$ V_{rms}

IV. CONCLUSIONS AND FUTURE WORK

A primary-side quasi-resonant control IC for flyback converter is proposed, and the hardware prototype has been designed and implemented. In the proposed control IC, a novel valley detector is integrated to automatically detect the valley voltage of the power switch. The power switch of the flyback converter can be turned on at the valley voltage precisely under different resonant frequency conditions without any extra components.

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