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Resonant Isolated DC-DC Converter for the LED Backlight Drive of the LCD TV Module

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Abstract

This paper presents a resonant isolated dc-dc converter for the LED backlight drive of the LCD TV module with a simple resonant half-bridge flyback converter power topology. The power topology structure of the proposed converter is isolated using the half-bridge flyback converter power topology with a transformer. The proposed converter switches complementarily its primary half-bridge switches and achieves high efficiency using the resonant circuit, composed of a resonant inductor and a blocking capacitor. The leakage inductance of the main transformer is used as the resonant inductor, and thus the proposed converter can be simplified. In this paper, the operational principle is analyzed, briefly, and a 100-W-class prototype is implemented based on the analysis. Then, it is shown that the proposed converter has good performance as a driver of the LED backlight drive of the LCD TV module through the experimental results of a 100 W prototype under a wide input voltage and load range.

Keywords*: Resonant isolated dc-dc converter, half-bridge flyback converter, PWM, resonant circuit, LED backlight drive, LCD TV module*

1. Introduction

The display market has undergone rapid growth during the recent digital multimedia broadcasting era, and numerous efficient power-driving techniques for the backlight unit of LCD TV have been investigated. Regarding power conversion, compact and economic topologies with electromagnetic interference (EMI) reduction are needed for low-power supplies for the low- and middle-priced TV market [1, 2]. Therefore, the flyback converter power topology is attractive because of its simple structure. Flyback converters have been generally applied to low-power switch-mode power supplies (SMPS) for low- and middle-priced TVs. However, the flyback converter requires a snubber circuit to suppress the voltage spike across the switch caused by the leakage inductance of the main transformer. Moreover, high *di*/*dt* or *dv*/*dt* due to hard switching increases the cost of solving the EMI problem and increases switching losses. Thus, the total converter efficiency is deteriorated and high frequency operation of the converter is limited [3-8].

To overcome these drawbacks, soft-switching techniques have been considered effective solutions. Half-bridge converters using the complementary pulse-width modulation (PWM) switching technique at their primary half-bridge switches [6-8] have been proposed because of their simple circuit configuration and ability to achieve zero voltage switching (ZVS). Resonant flyback converters with a half-bridge circuit structure, which can achieve ZVS operation of power switches as well as low switch voltage stress, are gaining in popularity. The advantages of the half-bridge converter over the conventional converter and the active clamp flyback converter are described in [7, 8].

Conventional converters have several problems, such as EMI noise and switching losses due to hard switching operation. In active clamp flyback converters, active

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switches must overcome a much higher voltage than the input voltage, which leads to a reverse recovery problem [7].

In this paper, a resonant isolated dc-dc converter for an LED backlight drive of an LCD TV module is presented. The proposed dc-dc converter has an isolated power structure using a flyback converter and half-bridge circuit topology and utilizes the pulse-width modulation (PWM) switching technique. The primary half-bridge switches are switched complimentarily, and the converter uses a resonant circuit network that includes the leakage inductance of the main transformer as the resonant inductance and the blocking capacitor as the resonant capacitor. In this way the proposed converter can be simplified. In this paper, the operational principle is analyzed simply, and a 100 W prototype is implemented based on the analysis. The proposed converter is verified to have good performance as a driver for an LED backlight of an LCD TV module by the results of experiments executed with wide input and load ranges.

2. Circuit Configuration of the Proposed Converter

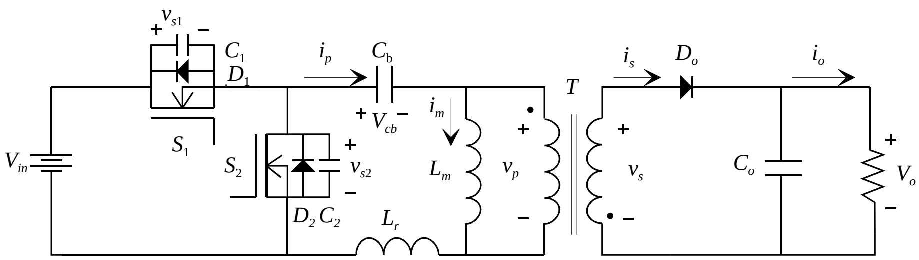

Figure 1. The Circuit Configuration of the Proposed Resonant Isolated Dc-Dc Converter

Figure 1 shows the circuit configuration of the proposed resonant isolated dc-dc converter using the half-bridge flyback converter structure. The main transformer T is modeled as the magnetizing inductance L_m, the leakage inductance L_r and an ideal transformer with the turn ratio of 1:n (=N_s/N_p). The leakage inductance L_r is used as the resonant inductance and is considerably lower than the magnetizing inductance L_m. The primary half-bridge switches S_1 and S_2 are switched complementarily and the duty ratio D is based on the turn-on duty of the switch S_1. The blocking capacitance C_b that is the resonant capacitor is large enough so that the capacitor voltage V_{Cb} is constant. Then, the average voltage of C_b is DV_{in}. The diode D_o is the secondary output diode. The output capacitance C_o is large enough so that the ripple component of the output voltage V_o is negligible. The load resistor denotes the LED backlight of the LCD TV.

3. Mode Analysis of the Proposed Converter

Figures 2 and 3 show equivalent circuits of each operation mode of the proposed converter and the theoretical operation waveforms of the proposed resonant isolated dc-dc converter, respectively. The steady-state operation of the proposed converter is divided into seven modes during one switching period T_s. Each mode of the proposed converter is determined based on the conduction states of the switches S_1, S_2 and their corresponding parallel diodes at the primary and the output diode D_o at the secondary. It is assumed that the primary current i_p flows in the negative direction under an initial steady-state condition before Mode 1 starts.

Mode 1 (t_1–t_2): At time t=t_1, the switch S_2 turns off. Then, the primary current i_p discharges the switch parallel capacitor C_1 and charges the switch parallel capacitor C_2. Because the capacitors C_1 and C_2 (C_1=C_2=C_S) have small values, the interval of this mode is very short. During this mode, the primary half-bridge switches are turned off

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simultaneously, and the primary current i_p and the magnetizing current i_m are constant. Therefore, this mode is termed the dead-time mode. Although the primary series inductance (=L_m+L_r) of the transformer resonates with the capacitances C_1 and C_2, this effect is not be exposed, because the resonant period is markedly larger than the dead time.

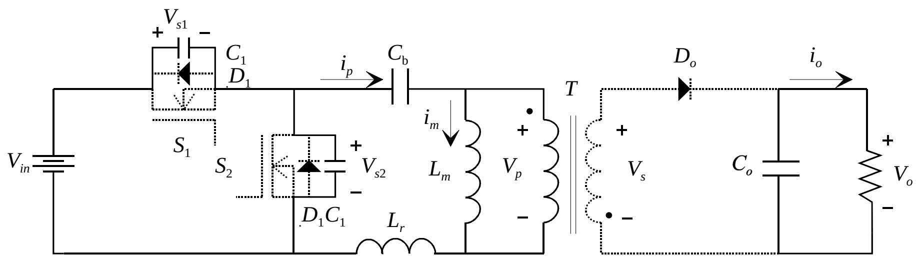
Mode 2 (t_2–t_3): When the switch voltage v_{s1} becomes zero at time t=t_2, the primary current i_p begins to conduct through the body diode D_1 of the switch S_1. After time t=t_2, a turn-on gate voltage v_{GS1} is applied to the gate of the switch S_1. The switch S_1 is turned on with ZVS before the primary current i_p changes its polarity. The blocking capacitor C_b and the primary series inductor are resonated, but the resonant period at this time considerably longer compared with one switching period T_s. Thus, the primary current i_p increases almost linearly, as follows:

$$i_p(t) = i_p(t_2) + \frac{(1-D)V_{in}}{L_m+L_r}(t - t_2) \tag{1}$$

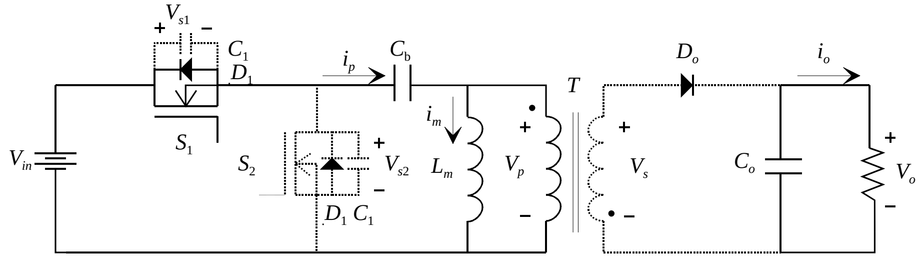
and then the magnetizing inductance L_m stores energy.

Mode 3 (t_3–t_4): At time t=t_3, the primary current i_p flows in the positive direction. The switch S_1 was turned on during Mode 2, and switch S_2 is off. The primary current i_p increases linearly due to the difference between the voltages of the input and the blocking capacitor C_b. In this mode, the electrical energy is stored in the magnetizing inductance L_m of the transformer.

Mode 4 (t_4–t_5): At time t=t_4, switch S_1 turns off. This mode is also a dead-time interval, similar to Mode 1, during which the primary half-bridge switches are turned off simultaneously. The primary current i_p charges the switch capacitance C_1 and discharges the switch capacitance C_2. Similarly to Mode 1, the primary current i_p and the magnetizing current i_m are constant.



(a) Mode 1 (t_1–t_2)



(b) Mode 2 (t_2–t_3)

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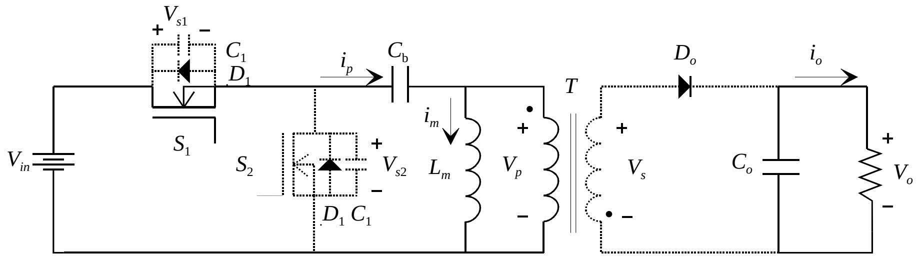
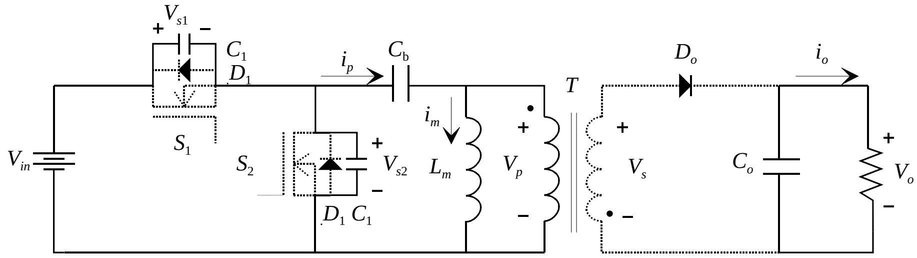
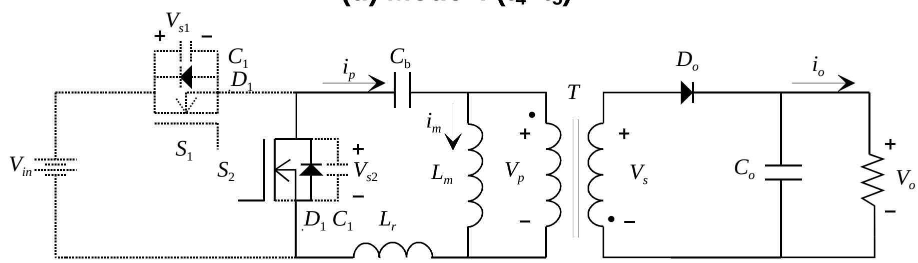


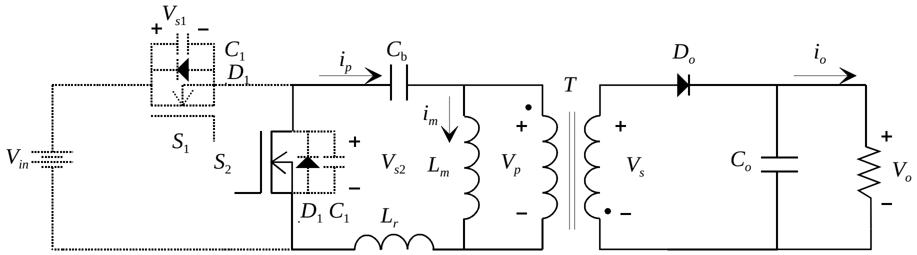
(c) Mode 3 (t_3–t_4)



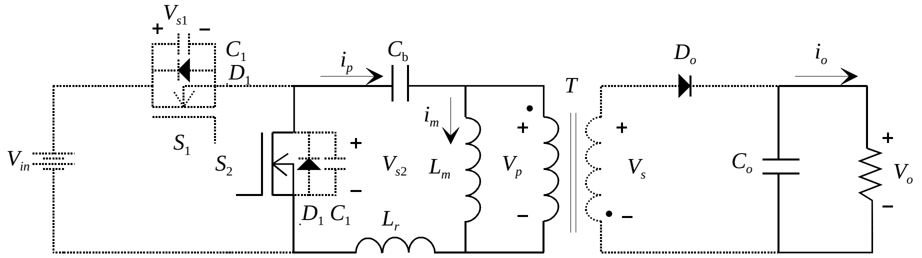
(d) Mode 4 (t_4–t_5)



(e) Mode 5 (t_5–t_6)



(f) Mode 6 (t_6–t_7)



(g) Mode 7 (t_7–t_8)

Figure 2. Equivalent Circuits of Operation Modes of the Proposed Dc-Dc Converter

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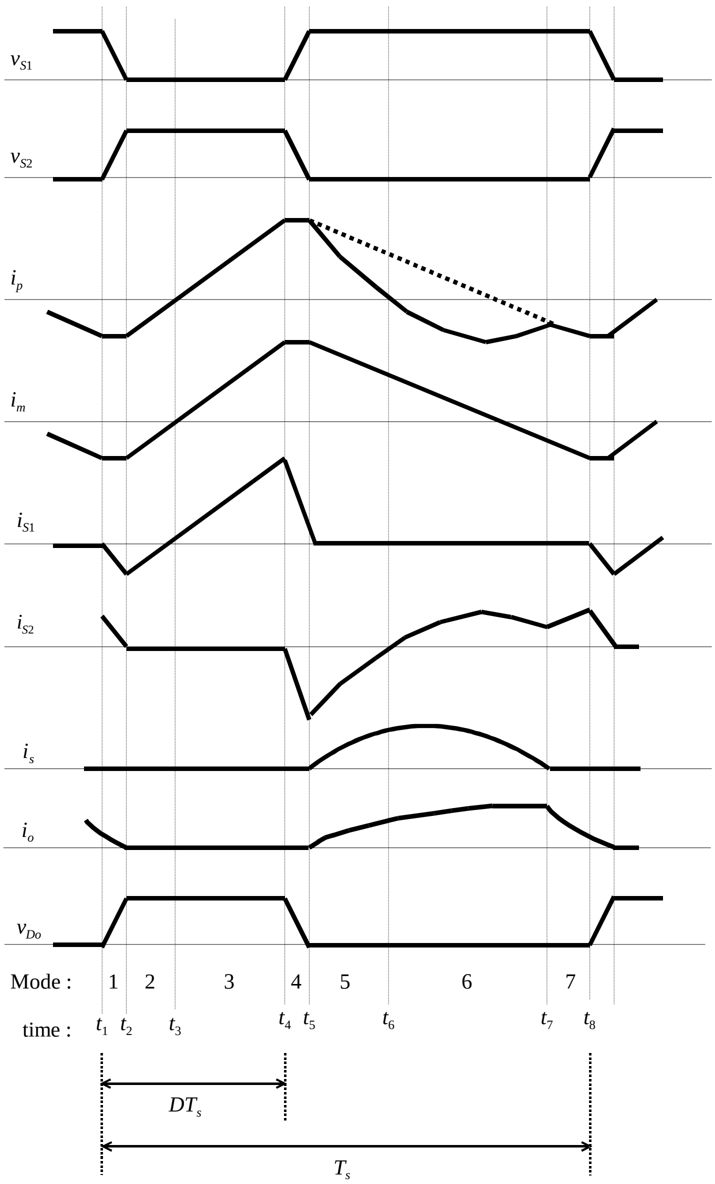

Figure 3. The Theoretical Operation Waveforms of the Proposed Resonant Isolated Dc-Dc Converter

Mode 5 (t_5–t_6): When the switch voltage v_{s2} becomes zero at time $t=t_5$, the body diode D_2 of the switch S_2 conducts the primary current i_p. After time $t=t_5$, a turn-on gate voltage v_{GS2} is applied to the gate of the switch S_2. The switch S_2 turns on with ZVS before the polarity of the primary current of i_p is changed. The voltage across the magnetizing inductance L_m is clamped by the reflected output voltage at the transformer primary. At the same time, the output diode D_o turns on, and the winding voltage polarity is changed. The blocking capacitor C_b, which is the resonant capacitor, and the leakage inductance L_r of the transformer resonates. The energy stored in the magnetizing inductance L_m is transferred to the secondary output stage. The difference between the primary current i_p and the magnetizing current i_m is reflected to the transformer secondary. The magnetizing current i_m and the primary current i_p are given by:

$$i_m(t) = i_p(t_5) - \frac{V_o}{nL_m}(t - t_5) \qquad (2)$$

$$i_p(t) = i_p(t_5)\cos\omega_r(t - t_5) - \frac{\frac{V_o}{n} - DV_{in}}{Z_r}\sin\omega_r(t - t_5) \quad (3)$$

where $\omega_r = 1/\sqrt{L_r C_b}$ is the angular resonant frequency and $Z_r = \sqrt{L_r / C_b}$ is the resonant impedance.

Mode 6 (t_6–t_7): While the magnetizing current i_m changes its polarity to negative at time $t = t_6$, the primary current i_p becomes negative. The switch S_2 and the output diode D_o have already turned on, and the switch S_1 is off. In this mode, a conduction loss occurs at only the output diode D_o. This mode ends when the transformer secondary current i_s becomes zero at time $t = t_7$.

Mode 7 (t_7–t_8): At time $t = t_7$, the transformer secondary current i_s is zero. The primary current i_p and the magnetizing current i_m are equal during this mode. The output diode D_o is turned off with zero current switching (ZCS) at the end of this mode. The next switching period is repeated when switch S_2 turns off.

4. Experimental Results

To verify the performance of the proposed resonant isolated dc-dc converter with complementary switching, a converter prototype was implemented based on the analysis described in Section 3 with the specifications shown in Table 1.

Table 1. Specifications of the Prototype Converter

Content	Value
DC input voltage	V_{in}=240–380 V
Maximum output power	$P_{o,\max}$=100 W
Switching frequency	f_s=100 kHz
Maximum turn-on duty	$D_{\max}$=0.45

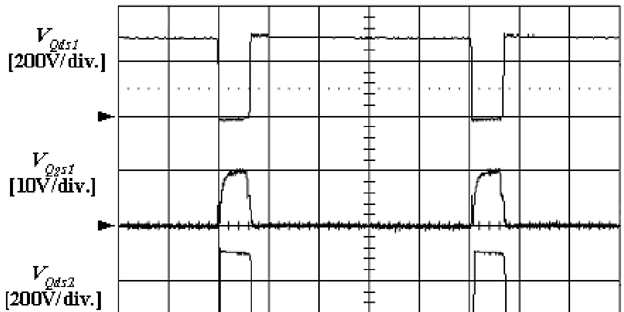

Figure 4. The Experimental Waveforms of the Drain-Source Voltage and Gate-Source Voltage of Switches S_1 and S_2

For the prototype converter, a current mode control IC was adopted with proportional and integral (PI) control to ensure system stability and a rapid transient response. The PWM signal is transferred to a high- and low-side driver through a hex buffer, and the delay time of the switches was set to be 200 ns to ensure ZVS operation.

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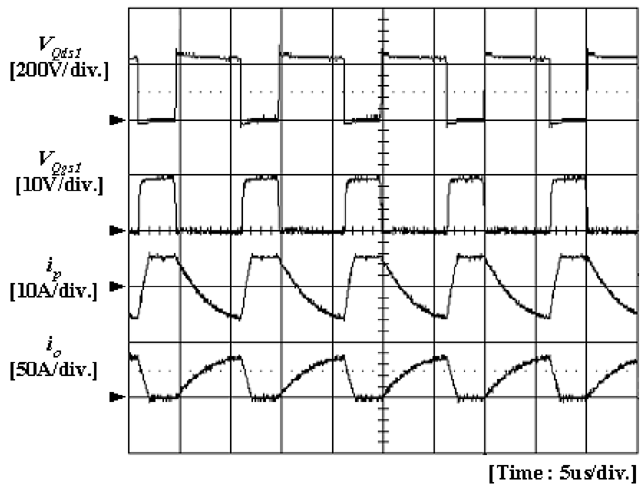
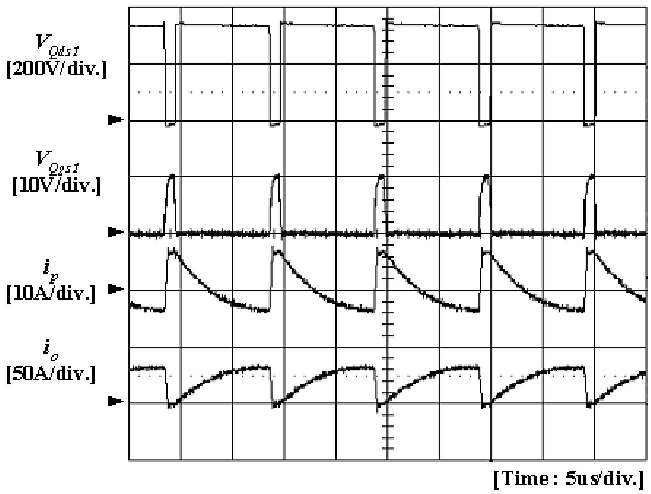


(a) V_{in}=240 V



(b) V_{in}=380 V

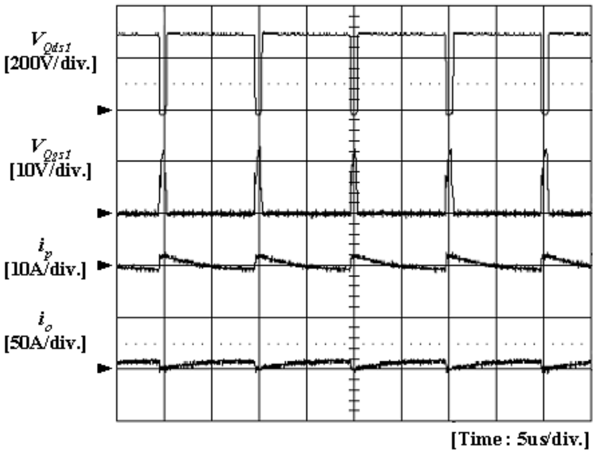
Figure 5. The Experimental Waveforms of the Drain-Source and Gate Voltages of Switch S_1 and the Primary and Output Currents With the Maximum Output Load At Each Dc Input Voltage

Figure 4 shows the experimental waveforms of the drain-source voltage and gate-source voltage of the switches S_1 and S_2. There is a time delay (dead-time) between the switches S_1 and S_2. The proposed converter is operated well with the complementary PWM switching.

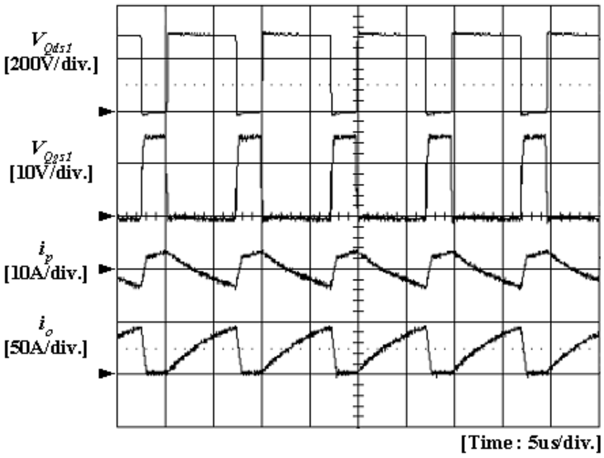
Figure 5 shows the experimental waveforms of the drain-source and gate voltages of switch S_1 and the primary and output currents with the maximum output load at each dc input voltage. The proposed converter operates with the maximum output load at each dc input voltage.

Figure 6 shows the experimental waveforms of the gate signal, the drain-to-source voltage for switch S_1 and the primary and output currents with light and full load conditions at the dc input voltage V_{in}=311 V.

Figure 7 shows a photograph of an LCD TV module with an LED backlight unit operated by the prototype converter. The picture of the module underwent gradation processing and is very bright and clear. The picture quality is excellent.



(a) P_o=25 W



(b) P_o=100 W

Figure 6. The Experimental Waveforms of the Gate Signal, the Drain-To-Source Voltage for Switch S_1 and the Primary and Output Currents with Light and Full Load Conditions At the Dc Input Voltage V_{in} = 311 V

Figure 7. Photograph of an LCD TV Module with an LED Backlight Unit Operated By the Prototype Converter

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Therefore, it can be confirmed that the proposed converter operates well with a wide dc input voltage and under various load conditions. The resultant total converter efficiency is 89% at the maximum output load ($P_{o,\max}$=100 W). This is very high compared with conventional converters, whose efficiency is usually ~75%.

5. Concluding Remarks

In this paper, a resonant isolated dc-dc converter for an LED backlight drive of an LCD TV module was presented. The proposed dc-dc converter has an isolated structure with a flyback converter and half-bridge circuit topology and utilizes the PWM switching technique. The primary half-bridge switches are switched complimentarily, and the converter uses a resonant circuit network that includes the leakage inductance of the main transformer as the resonant inductance and a dc blocking capacitor. Thus, the proposed converter has been simplified. In this paper, first, the operational principle was analyzed briefly, and then experimental results of a 100 W prototype implemented based on the analysis are shown. The proposed converter has good performance as a power supply for driving an LED backlight of an LCD TV module by the results of experiments executed under conditions of wide dc input and output load ranges.

Acknowledgments

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