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Flyback converter using SiC power-MOSFET to achieve high frequency operation over 10 MHz

Nobuo Satoh†, Yasuyuki Nishida‡

Department of Electrical and Electronic Engineering, Chiba Institute of Technology
2-17-1 Tsudanuma, Narashino, Chiba, 275-0016 Japan
E-mail: †satoh.nobuo@it-chiba.ac.jp, ‡yasuyuki.nishida@it-chiba.ac.jp

Abstract—We have developed of the isolated flyback converter which can be operated at switching frequencies beyond 10 MHz. We estimated the high frequency characteristics of passive devices in various places of the converter circuit. The flyback converter has been examined by means of very high switching frequency of 20 W. In order to verify the fast switching operations, the input and output voltages with currents are measured, the transient behavior of the converter without/with snubber were experimentally estimated both in current continuous and discontinuous operation.

1. Introduction

Flyback converters also face to the electrical insulation used in the majority of small power switching supplies [1, 2]. It is required in the regulations that a power supply ensures the electric insulation to avoid damage to precision instruments, to prevent electric shock to the human body, and to intercept conduction noise. The insulation device in the configuration is a pulse transformer as the choke coil. Plainly, the gate driving circuit must be insulated with keeping detachment of control and power circuits.

In DC power supplies, the switching operation with high-speed can decrease the quantity of energy treated in one cycle operation [3]. This promotes the downsizing of the passive elements of the inductor and the capacitor. However, parasitic impedances in the circuit decide high frequency with the high-speed switching operation. The switching loss occurs because of the surge voltage, the tail current, and ringing phenomena originated in both circuit patterns and switching device parasitic components. Moreover, the destruction of circuits and devices is eventually induced by the heat generated by losses. Thus, one of our goals is aimed at the suppression of losses.

In this study, we showed a flyback converter of 20 W output-class without/with a snubber circuit at 1MHz switching operation. The transient behavior of the converter was experimentally estimated both in current continuous and discontinuous operation. It described for the experimental study aimed at achieving the 10 MHz switching operation with an output-power of tens of watts [4].

2. Experimental setup

The flyback converter under test is presented in Figure 1. We designed for high-power output as 20 W at 1 MHz operation.

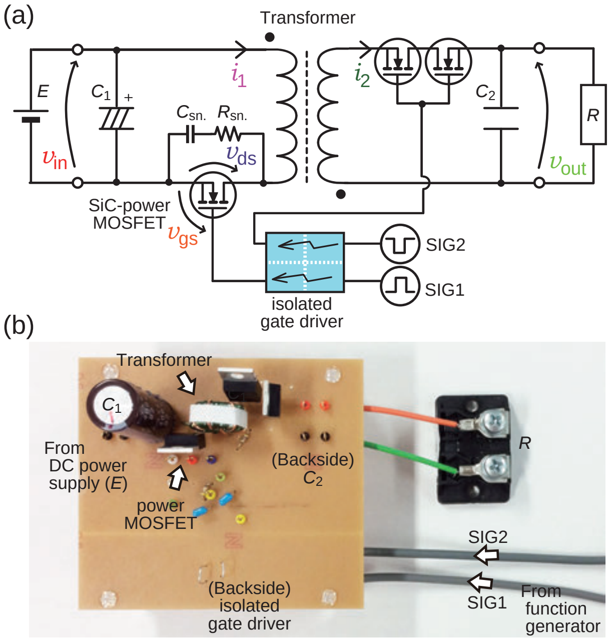

Figure 1: (a) Schematic circuit diagram of the flyback converter using the isolated gate driver and the transformer. (b) Photograph of the flyback converter

In the primary side of the pulse transformer, corresponding to the power input side, the electric power supply (E) is connected. As an important matter, to examine the circuit behavior, there were need to suppress inadvertent oscillation phenomenon. Thence, the prepared power supply is a series-regulator type for stabilizing DC power source (GPO110-3; Takasago Ltd.) rather than the switching type of general-purpose one. In order to manage the maximum attainment voltage, a capacitor (C_1) was connected with a charge capacity of 82 μF (withstand voltage: 400 V; Nippon Chemi-Con Corp.) to avoid the instability of voltage supplied at the primary side.

The secondary side of the transformer is connected to a load at power output side. For high-speed switching operation, the capacitor (C_2) is worked as the smoothing capacitor on the output side. A multilayer ceramic capacitor of surface mounts type has been selected as a candidate for the high-frequency application. It is preferable rather than an electrolytic capacitor [5]. The reason is the neglected lifetime deterioration caused by heat, the smaller spatial volume, the high permissible ripple electric current, and the small equivalent series resistance (ESR). These features are strongly expected to raise significant advantages to the miniaturization of the power supply circuit with the high-speed switching. Based on the switching frequency (f_{sw}) and the accepted ripple rate, ceramic capacitors are connected with ten-pieces in parallel of surface-mount type as 0.1 μF (withstand voltage: 50 V; Murata Manufacturing Co., Ltd). Non-inductive load resistor 5 Ω was terminated as a resistance value to the output.

2.1. Switching device

We have selected the SiC-MOSFET as a switching device, which are evaluated in the flyback converter. There is expected to perform at a high withstand voltage and a large current, being applied in the switching device [6]. The SiC MOSFET (SCTMU001F; Rohm) is a power MOSFET made of a silicon carbide semiconductor with two different implanted regions - p-body region and n-source region - to provide high voltage and the large current capabilities. The resistance and capacitor (*RC*) snubber circuit connected with the power-MOSFET in parallel was inserted for the suppression of the surge voltage. The circuit parameter of *RC* snubber calculated referring to the guideline for the circuit design by reference [7], and employed such as R=100 Ω, C=800 pF.

2.2. Gate driver

Frequency characteristics of the isolated gate-driver that functions as the controlling of electric potential level for the power MOSFET in the flyback converter are shown in Fig. 2. In this case, the band width is approximately 30 MHz. We have confirmed that the consideration of the phase delay is necessary for the phase margin in a switching operation that exceeds 10 MHz.

2.3. Transformer

In the flyback converter, a secondary coil of the pulse transformer is employed as a choking coil [1]. It is also well known that power loss at high-speed switching operation limits the use of magnetic components [8]. A transformer for the flyback converter with high-frequency operation has been designed. The frequency characteristics of the transformer with toroidal-winding and Liqualloy$^{\mathrm{TM}}$ material has been appraised.

Figure 3 shows the frequency response of the transformer as primary winding and secondary winding, respec-

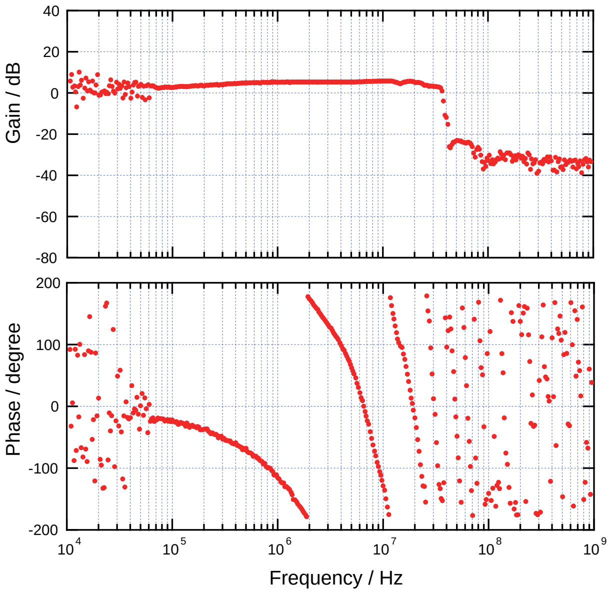

Figure 2: Frequency characteristic of the gate driver.

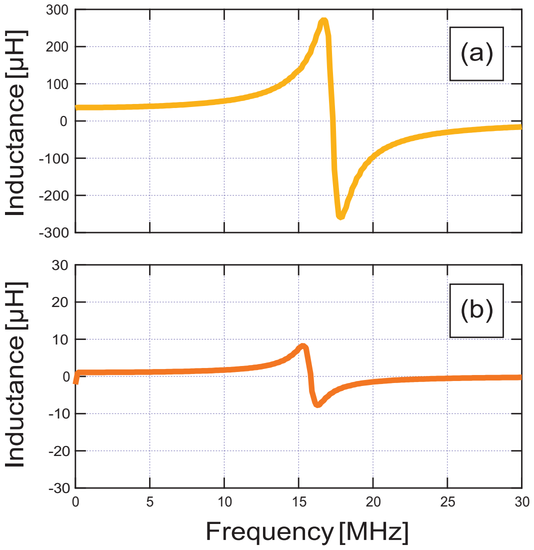

Figure 3: Frequency response of the transformer (a) primary winding (b) secondary winding.

tively. The inductance and coupling coefficient of the transformer were measured at an operation frequency which equals 10 MHz. The inductance of primary side was 20 μH and the secondary side 2 μH. The coupling factor was estimated at 0.98 by an estimated-circuit of open-short-test. In general, a coupling coefficient evaluated more or equal to 0.95 is required for the transformer [1].

2.4. Rectifying device

Firstly, a SiC Schottky barrier diode (SBD) was adapted to the rectifying device (D). However, in the above operating frequency 1 MHz, the flyback converter circuit was not a stable operation mode. One of the reasons was due to the frequency dependence of the rectifying characteristics of the diode (D). In the 1 MHz operation of the diode as shown in the Fig. 4, it does not have sufficient rectifying characteristics.

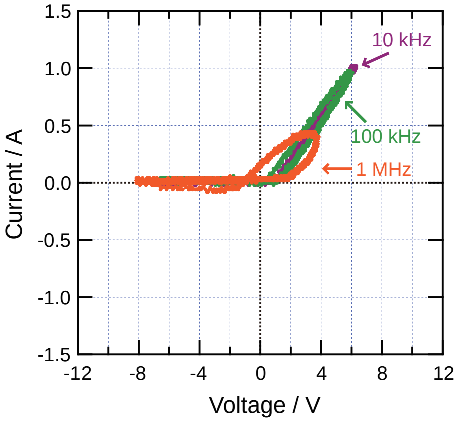

Figure 4: Rectifying properties of diodes according to the operating frequency.

Consequently, we utilized the two of the power MOSFET, which is a switching device. The rectification in the secondary side was realized by the phase modification.

3. Results and Discussions

All signals were simultaneously observed by two insulation oscilloscopes (TDS2024B; Tektronix Inc.) and two current probes (TCP305; Tektronix Inc.) while analyzing the transient behavior of the flyback converter. The measured states variables were the following: the gate-source voltage (v_{gs}), the drain-source voltage (v_{ds}) of the power MOSFETs, the input voltage (v_{in}), the current of the primary side (i_1), the output voltage (v_{out}), and the current of the secondary side (i_2).

The switching trigger signal is transmitted to the isolated gate driver through the pulse generator (81101A; Agilent). The duty ratio was set within the range of 20% to 50% in order to avoid the continuous-mode operation of the flyback converter. To achieve and evaluate the fast switching operation for all power MOSFETs, the gate-source voltage (v_{gs}) were set at the pulse-shaped waveform with the binary level at 0 V (on-state) and 12 V (off-state).

3.1. Without *RC* snubber

The waveforms of the gate-source voltage (v_{gs}) and the drain-source voltage (v_{ds}) at f_{sw} = 1 MHz switching operation is shown in Figure 5. Here, The DC voltage of the input-side was 90 V applied. The drain-source voltage (v_{ds}) waveform shows the surge voltage reached at approximately 500 V of its maximum. The discharge current from the choking coil was observed by the secondary current (i_2), which caused ringing phenomena. Nevertheless, the behavior of the flyback converter was scrutinized reliably. The output provides the direct voltage 10 V and the direct current of 2.0 A.

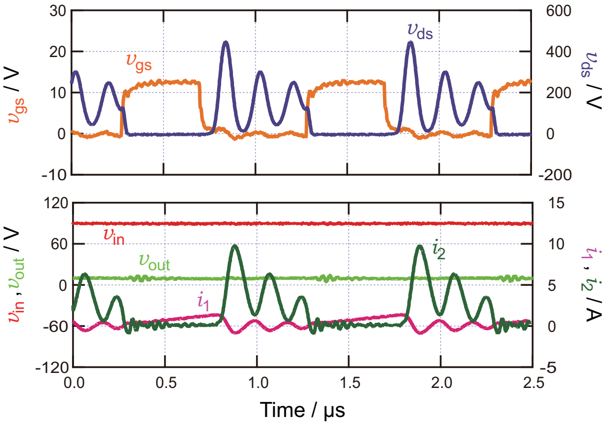

Figure 5: Oscillograms of v_{gs}, v_{ds}, v_{in}, v_{out}, i_1 and i_2 for the flyback converter without *RC* snubber at f_{sw}=1 MHz in 20 W output.

3.2. With *RC* snubber

Figure 6 shows the waveforms of voltage and current that we designed the flyback converter with the snubber circuit at 1 MHz switching operation in 20 W output-power, the output supplies the direct voltage 10 V and the direct current of 2.0 A. The drain-source voltage (v_{ds}) waveform shows the surge voltage reached at approximately 300 V of its maximum. The surge voltage was suppressed for certain, it has been confirmed experimentally. In addition, the discharge current from the choking coil was observed by the secondary current (I_2), which not caused ringing phenomena.

On the other hands, the DC voltage of the input-side was 100 V applied. Apparently the loss was increased by that they have installed the *RC* snubber circuit. It was confirmed that remain, transient behaviors of the secondary current (i_2) correspond to the discharge current from the choking coil according to the switching operation.

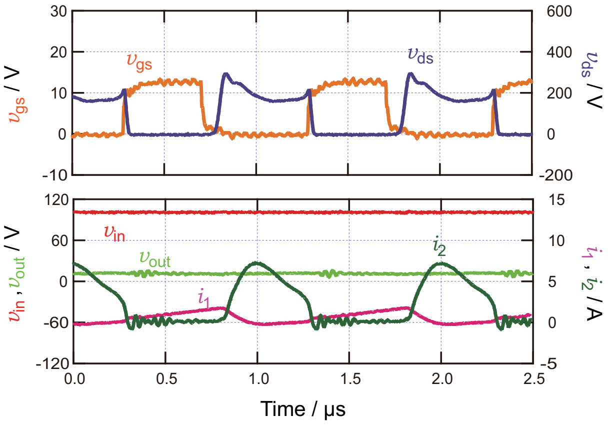

Figure 6: Oscillograms of v_{gs}, v_{ds}, v_{in}, v_{out}, i_1 and i_2 for the flyback converter with *RC* snubber at f_{sw}=1 MHz in 20 W output.

4. Actual and future tasks

We had clarified that there is a limit of 3 MHz operation, experimentally. Its main cause might be the parasitic capacitance of the switching device. We verify at 10 MHz operation of flyback converter, by switching-device having a small parasitic input capacitance is employed.

Moreover, we attempt the suppression of the switching losses by the self-induced soft switching operation due to the ringing frequency of the secondary current, that had shown in the flyback converter without snubber during the switching operation at f_{sw}= 1 MHz.

5. Summary

We have fabricated the flyback converter that has power output of the 20-watt class at f_{sw}=1 MHz. Based on evaluating the device performance of the circuit, the rectification by the switching device is carried out instead of a diode. The circuit was able to operate while ensuring the electrical insulation by the isolated-gate-driver and the transformer.

Acknowledgments

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