Paper

Simplified Resonant DC-DC Converter with High Frequency Drive

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We present a new circuit for resonant dc-dc converter of forward type made of a small number of components which is almost the same in a fly back converter as a smoothing inductor and a free-wheel diode are removed. As parasitic elements like stray capacitors and inductors are operating as a part of a resonant circuit, high frequency switching of low losses can be obtained. A leakage inductance of the transformer is utilized as a inductor of resonant circuit although it prevents the output power going through the transformer in conventional converters.

Key words: resonant converter, high frequency switching, Leakage inductance, leakage transformer

1. Introduction

Magnetizing inductor of transformer is utilized for the resonant inductor in all of the already developed circuits of resonant dc-dc converters using the output transformers. (1) As the switching frequency becomes higher for the aids of light weight and small size, the output transformer is constructed by low permeability core of small loss in high frequency operation or without core. In this case, the power transmitted through transformer is limited by increment of the leakage inductor. We can realize a new converter utilizing the leakage inductors instead of magnetizing one by means of connecting another resonant capacitor to the secondary winding of the transformer. This capacitor is only one component adding to the fly back converter. However, there is a clear difference in polarity of transformer windings between this converter and the fly back one.

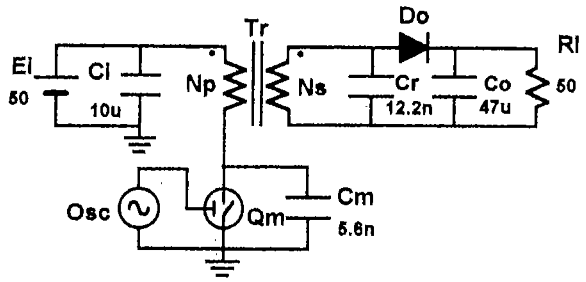

Fig.1 Simplified DC-DC Converter

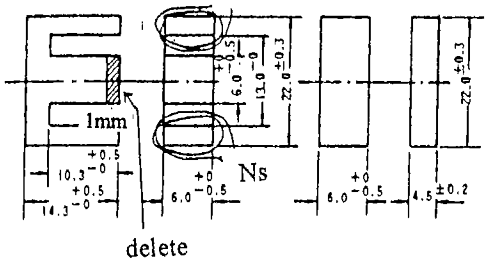

Fig.2 Leakage Transformer

We present an experimental circuit of simplified dc-dc converter in Fig.1. Ei is a dc power source. Ci is an input capacitor, that is, a bypath capacitor of high frequency current. Tr is a leakage transformer with the primary winding Np and the secondary one Ns. Qm is a power MOSFET as a main switch driven by an oscillator Osc. Cm is a main resonant capacitor. Cr is a resonant capacitor. Do is a first recovery diode. Co is an output capacitor smoothing the output voltage delivered to a load resistor Rl. Fig.2 shows the construction of the leakage transformer Tr. A magnetic core (E-I type ferrite core) has a leakage path with air gap between Np and Ns.

2. Analysis

Fig.3 is the equivalent circuit for analysis of the experimental one shown in Fig.1. Ci is eliminated as the output impedance of Ei is zero. Lp and Ls are the leakage inductances of Np side and Ns side respectively. Le and Re are the magnetizing inductance and the equivalent resistor of power loss of Tr. Cm includes a drain capacity of Qm and a stray capacity of Np. Dm operates sufficiently in this circuit although it isn't a first recovery diode because reverse voltage isn't applied when Dm is ON state. Values of Ls, Cr, Do, Co and Rl are equivalent ones transferred from the secondary Ns side to the primary Np side.

Fig.4 shows wave forms given by SCAT simulator. (2) v_{Qm} and v_{Cr} in (a) are voltages of the main switch Qm and the resonant capacitor Cr respectively. $i_{Qm}+i_{Dm}$ in (b) are currents of the main switch (Qm and Dm) and the output diode Do.

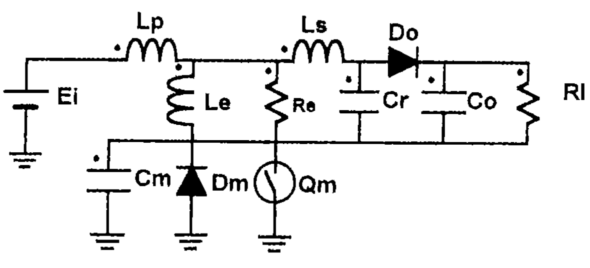

Fig.3 The Equivalent Circuit for Analysis

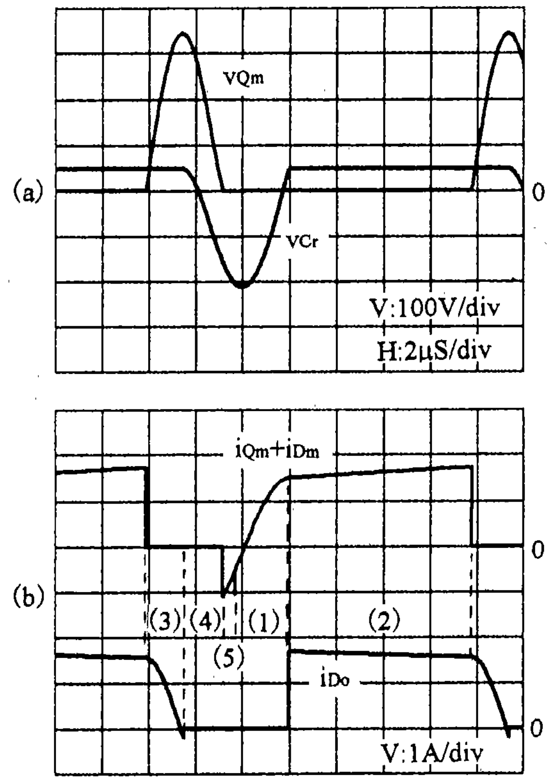

Fig.4 Voltage and Current Wave Forms in Simulation
(a) v_{Qm}: Voltage of Qm
v_{Cr}: Voltage of Cr
(b) $i_{Qm}+i_{Dm}$: Current of MOSFET
i_{Do}: Current of Do
Lp = Ls = 100μH Le = 1mH
Cm = 5nF Cr = 8.2nF Co = 47μF
Fs = 72kHz Toff = 3.8μS
Ei = 50V Rl = 47.2Ω

Fig.5 shows a transition of states in one switching cycle. State (1) to (5) are corresponding to period (1) to (5) in Fig.4 (b). In state (1), load current of Rl is delivered from Co. At the same time, current i_{Qm} of Qm increases as the dc source Ei is applied to Lp, Ls and Cr. Alternative current of Le can negligible as Le ≫ Lp and Ls. Voltage v_{Cr} of resonant capacitor Cr increases by means of charging by i_{Qm}. When v_{Cr} becomes equal to the output voltage, Do turns ON and state changes to state (2). Current from Ei flows through Lp, Ls, Do, Co//Rl and Qm. State transition from (2) to (3) happens when Qm turns ON. As the voltage of Cm is zero in state (2), vCm, that is, v_{Qm} increases from zero. v_{Cm} increases by charging current through Ei, Lp, Ls Do and Co//Rl. At the instant when v_{Cm} becomes the maximum voltage and current iDo is zero, Do turns OFF and transition from (3) to (4) occurs. Cm is discharged through Cr, Ls, Lp and Ei. When v_{Cm} becomes zero, Dm turns ON and transition from state (4) to state (5) occurs. i_{Dm} approaches to zero in this state and Dm is still in ON. While Dm is ON, Qm turns ON and transition from state (5) to state

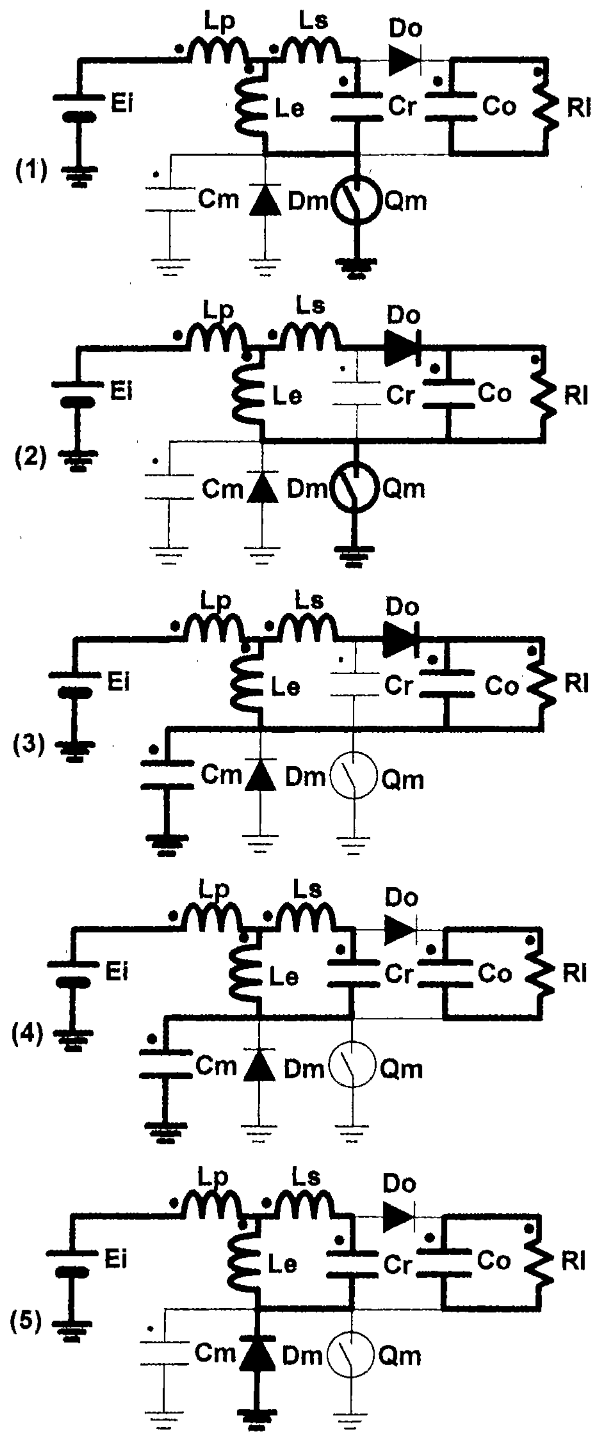

Fig.5 Transition of states in One Switching Cycle
(1) Qm is ON still Do is OFF.
(2) Do is ON.
(3) Qm is OFF still Do is ON.
(4) Do is OFF.
(5) Dm is ON.

(1) occurs. Precisely speaking, when i_{Qm} is negative, Qm and Dm are ON. As Dm has, however, a forward voltage drop, the great part of the current passes through Qm of the small

resistance.

As the result of one switching cycle mentioned above, the turn-on loss of Qm is extremely small as Qm turns ON when v_{Qm} is zero. And the turn-off loss of Qm is small as v_{Qm} arises from zero voltage and Qm turns OFF rapidly.

3. Magnetization of Core

We consider magnetization of transformer's core in comparison with our circuit and fly back converter. The magnetization current i_{Le} in our circuit shown in Fig.6 (a) is the difference of the input current ii and the output current io. On the other hand, i_{Le} in the fly back converter shown in Fig.6 (b) is the sum of ii and io. Therefore, the magnetization current in our circuit is smaller than that in the fly back converter. Moreover, we can make the dc magnetization current zero in the next condition. We get

$\eta EiIi = EoIo$ --- (1),

where η: conversion efficiency,

Ei: dc input voltage,

Ii: dc input current,

Eo: dc output voltage

and Io: dc output current.

In Fig.6 (a), we get the next expression on the dc magnetization current I_{Le}.

$I_{Le} = Ii - Io$ --- (2)

From expression (1) and (2), we get

$I_{Le} = Ii\,(1 - \eta Ei/Eo)$. --- (3)

When we make $Eo = \eta Ei$, I_{Le} becomes zero. That is, the operating point of the transformer's core is the center of B-H characteristics.

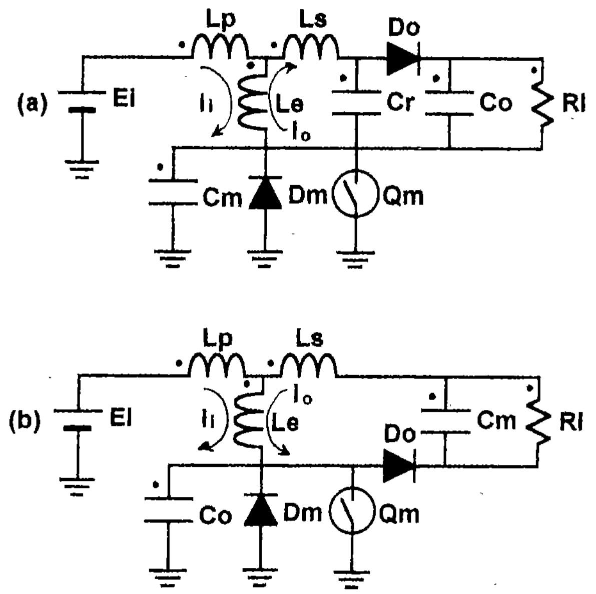

Fig.6 Magnetizing Current of Transformer's Core

(a) New Circuit

(b) Fly Back Converter

4. Experimental Results

The experimental circuit is shown in Fig.1. In this circuit, Ei = 50V, Eo = 44V, Cm = 5.6nF, Cr = 12.2nF, Co = 47μF. We use a E-I type ferrite core (TDK:FEI-22/PC40) for the transformer Tr shown in Fig.2 which is usually used in the converter of 15W output power. And Lp = Ls = 20μH and Le = 200μH are given by winding 17 turns for each and by adjustable deleting the center magnetic path. Semiconductor switches are Qm: Power MOSFET 2SK1500 (NEC) and Do: Fast Recovery Diode ESAD95-4 (Fuji Elec.).

Fig.7 shows voltage and current wave forms of Qm and Do. Fig.8 shows the experimental results on the switching frequency Fs and the conversion efficiency η vs. the output current Io. In this experiment, Fs is controlled as keeping the output voltage Eo = 44V. We can get a high conversion efficiency $\eta \fallingdotseq$ 90% in the output current range from 0.5A to 2.4A.

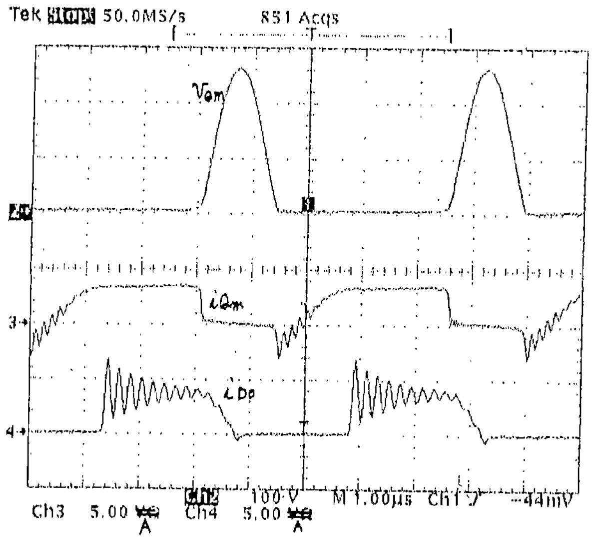

Fig.7 Voltage and Current Wave Forms of Qm and Do

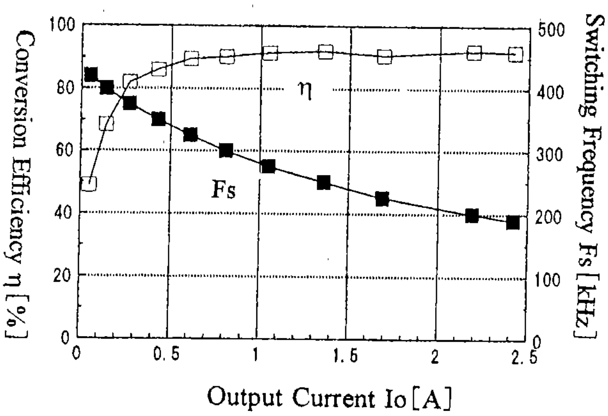

Fig.8 Switching Frequency Fs and Conversion Efficiency η vs. Output Current Io

Fig.9 shows the non-saturation region and saturation region of the transformer's core vs. the output current Io. The output voltage Eo is adjustable without saturation from Eomin to Eomax. We can see that the saturation of the core occurs in the operating range far from Eo = 44V, that is, the condition of the expression (3).

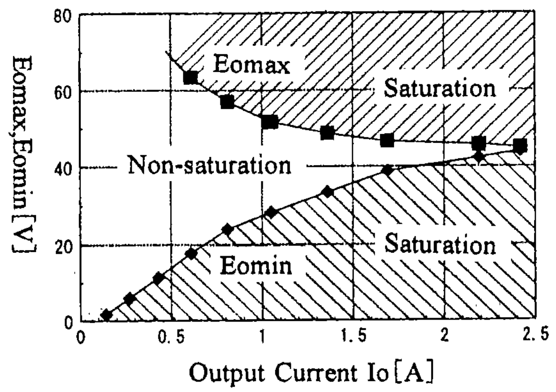

Fig.9 Non-saturation Region and Saturation Region

5. Conclusion

We can realize a new dc-dc converter with a small number of components by means of utilizing leakage inductances of the transformer. All of the parasitic elements are included in the equivalent circuit like stray capacitors, stray inductors and capacitors between electrodes of switching elements. Therefor, this converter can operate in high switching frequency with high efficiency of small size and light weight. This is suitable for a onboard converter supplied by a dc bus line with a little voltage change or by the output of a switching rectifier with unity power factor.

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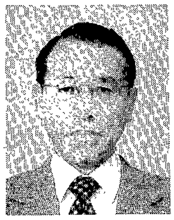

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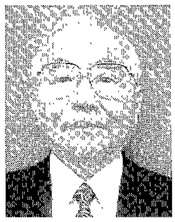

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