NOISE CHARACTERISTICS OF SIMPLIFIED FORWARD-TYPE RESONANT CONVERTER

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1. Introduction

The problem of noise generation due to PWM switched-mode power converter has been widely noticed from the viewpoint of Electromagnetic Interference(EMI). Many kinds of topologies for resonant converters have been developed both to overcome this noise problem and to attain high power efficiency. It is reported in references[1][2][3] that resonant converters which are derived from PWM converter using resonant switch show much lower noise characteristics than PWM converter, and that current-mode resonant converter is more sensitive to stored charge in rectifying diode than voltage-mode counterpart concerning surge generation at diode's turn-off. On the other hand, above mentioned resonant converters have defect of high-voltage stress on semiconductor switch and complicated circuit configuration.

Hence, the simplified Forward-type resonant converter has been proposed and investigated[4][5] due to its prominent features of simplicity of circuit configuration, low voltage stress and high stability. However, its noise characteristics still remain unknown.

The purpose of this paper is to study quantitatively the noise characteristics of this simplified Forward-type resonant converter by experiment and analysis. The influence of parasitic elements and stored charge in rectifying diode on noise generation has been clarified.

2. Modeling for Noise Analysis and Circuit Operation

The circuit configuration of the simplified Forward-type resonant converter is shown in Fig.1, where Ct is required to suppress the voltage surge across transformer during Dout off period. Waveforms of MOS-FET voltage VDS and current i_{DS} are shown in Fig.2 with states of circuit operation. Figure 3 shows the high-frequency equivalent circuit model with parasitic elements. Definitions of symbol used in these figures are as follows;

Ei:Input voltage, Eo:Output voltage, Lt:Magnetizing inductance, Lr:Resonant inductor, Cr:Resonant capacitor

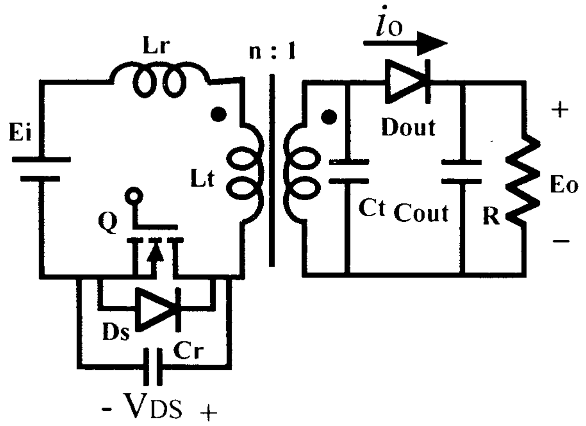


Fig.1 Simplified forward resonant converter.

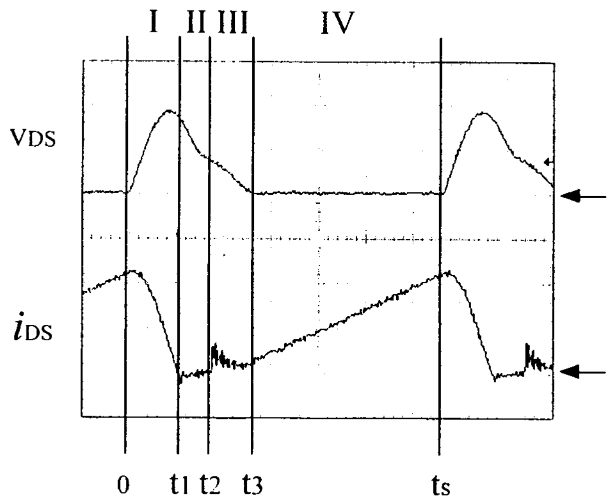


Fig.2 Waveforms of the converter.

Lkp, Lks : Leakage inductance of transformer and line inductance
Coss:Drain-source capacitance of MOS-FET
Cdo:Depletion capacitance in diode Dout
Cout:Output Capacitor
Ds:Body diode of MOS-FET
n:Turns ratio of transformer windings

Table 1 shows the states of circuit operation in typical mode

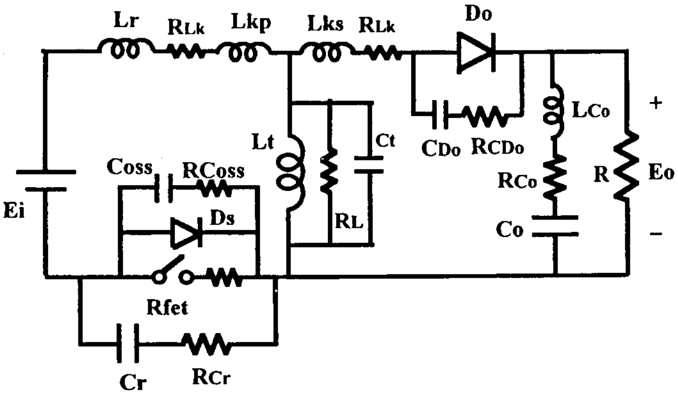
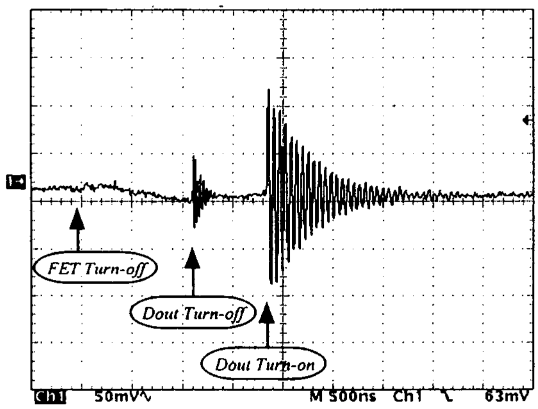


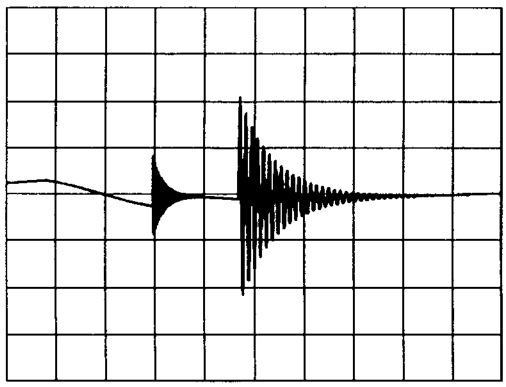
Fig.3 High-frequency equivalent circuit.

Table 1 States of circuit operation.

	FET : Q	Diode : Dout
STATE I	**OFF**	**ON**
STATE II	**OFF**	**OFF**
STATE III	**OFF**	**ON**
STATE IV	**ON**	**ON**

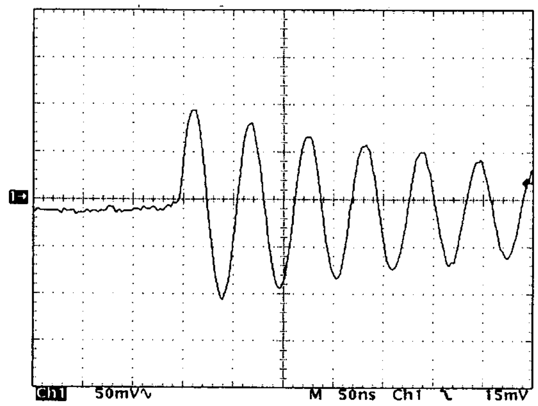


(a) Experimental

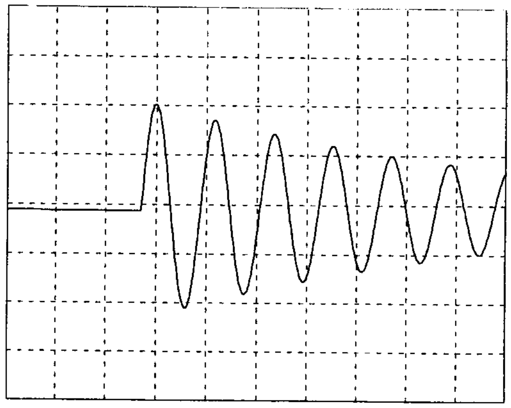


(b) Calculated

Fig.4 Noise voltage Eo (Ct=660pF).
(50mV/div., 500ns/div., Ei=18V, Eo=5V, R=10Ω, fs=150kHz, Lr=50μH, Cr=4.7nF, Lt=250μH, Cout=100μF, Lco=6nH, Lks=130nH)

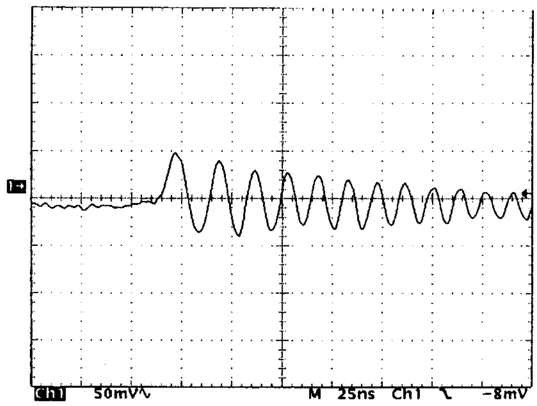


(a) Experimental

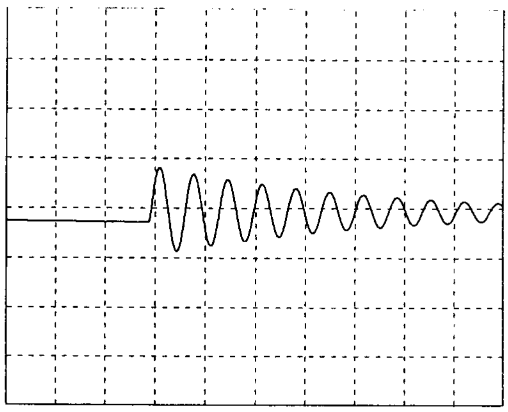


(b) Calculated

Fig.5 Surge voltage in Eo at Dout turn-on.



(a) Experimental



(b) Calculated

Fig.6 Surge voltage in Eo at Dout turn-off.

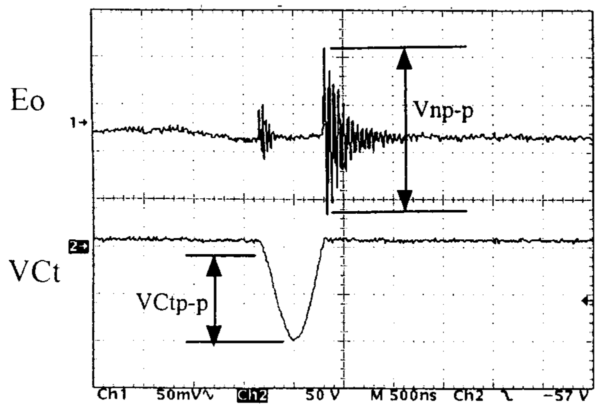


Fig.7 Noise voltage Eo and transformer voltage VCt. (Ct=440pF)

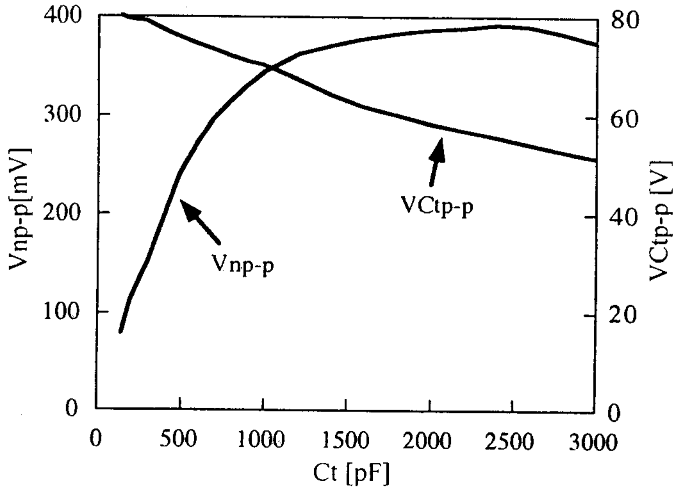


Fig.8 Trade-off between Dout turn-on surge Vnp-p and VCt.

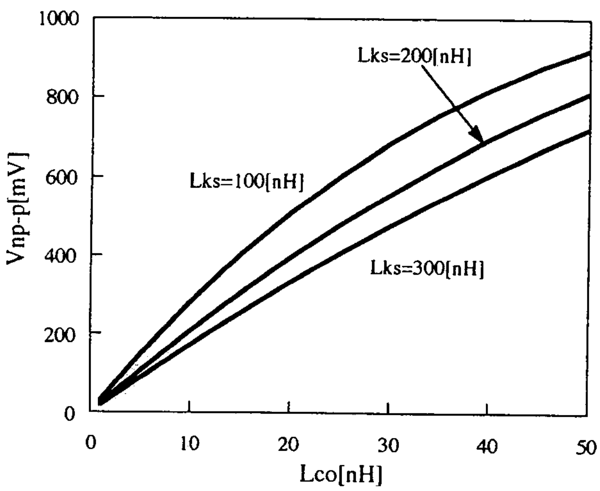


Fig.9 Influence of Lco(ESL in Cout) on Vnp-p .

of this converter. STATE I begins when the transistor Q turns off, and the resonance occurs by Cr and Lr. In this state, the transformer voltage VCt is clamped at the output voltage. The transition from STATE I to STATE II occurs at the time t1 when the output diode Dout turns off. In STATE II, the transformer voltage VCt and the voltage VDS across resonant capacitor Cr change in resonance fashion due to Lr, Ct and Cr. STATE III starts after the output diode Do turns on. The equivalent circuit of this state is the same as that of STATE I. This state lasts until the VDS reaches to zero. The switch must be turned on while the body diode in FET turns on after t=t3 in Fig.2 to attain zero voltage switching. In STATE IV, the input current increases linearly in time. The energy is transferred from input to output during the intervals of STATE I, III and IV.

3. Experimental and Calculated results

Waveforms of the output stage are shown in Fig.4. In this experiments with Ct=660pF, multi-layered ceramic capacitor are used as output capacitor Cout. It is found in this figure that two kinds of surges occur at Do turn-off and at Do turn-on. Figure 4 also shows the comparison of experimental surge with calculated one. This calculated waveform has been obtained using the high-frequency circuit model shown in Fig.3 and the simulator for switching regulator (SCAT Ver.K.530)[6][7]. Both experimental and calculated waveforms agree well. The slight difference between experimental and calculated waveforms for Dout turn-off surge is due to lack of sampling rate of oscilloscope. Next, these turn-on and turn-off surges are examined in details in Figs. 5 and 6. Figure 5 shows the Dout turn-on voltage surge, where time scale is 50ns/div. and voltage one 50mV/div.. Both experimental and calculated waveforms agree accurately. This surge has frequency component of 17MHz. The amplitude of this surge is influenced by Lks (leakage and line inductance), Ct and Lco (ESL in Cout). And, the surge frequency mainly comes from Lks and Ct. On the other hand, the surge voltage at Dout turn-off is shown in Fig.6. This surge has frequency component of 60MHz to 80MHz which is much higher than Dout turn-on surge, and the surge frequency is mainly affected by Lks and Cdo. The reason that the frequency of this surge changes from 60MHz to 80MHz is due to the change of depletion capacitor Cdo which is in inverse proportion to applied voltage.

Figure 7 shows the noise voltage Eo and transformer voltage VCt for Ct=440pF where Vnp-p depicts the peak to peak voltage of Dout turn-on surge and VCtp-p the negative peak voltage stress that is applied to rectifying diode Dout.

It is found from Fig4 and Fig.7 that Vnp-p decreases as Ct decreases. Fig.8 shows the influence of Ct on Vnp-p and VCtp-p. This figure demonstrates that there exists the relationship of trade-off between Vnp-p and VCt. Figure 9 shows the influence of Lks (leakage and line inductance) and Lco (ESL in Cout) on the surge amplitude at Dout turn-on. This figure shows that the surge peak-to-peak voltage Vnp-p is proportional to Lco, and that it is in inverse proportion to parasitic inductance Lks.

4. Conclusions

The noise characteristics of simplified forward -type resonant converter has been studied by experiment and simulation. The discussion is summarized by following conclusions.

(1)There appears two kinds of voltage surge with high-frequency component in output stage when rectifying diode turns on and turns off.
(2)There exists the trade-off between amplitude of diode turn-on surge and voltage stress of diode.
(3)Turn-on surge amplitude is proportional to parasitic inductance of smoothing capacitor, and inversely proportional to leakage inductance of transformer.

References

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