ANALYSIS OF NOISE CURRENT CANCELLATION MECHANISM IN BALANCED BOOST SWITCHING CONVERTER

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Abstract: We proposed a concept of balanced switching converter circuit, which is an effective way to reduce the common-mode conducted noise by current cancellation. In this paper, the path of the noise current in a balanced boost converter circuit is investigated using a current probe. By measuring current waveforms and frequency spectra of the parasitic capacitances and the frame ground line, the mechanism of the common-mode noise reduction by current cancellation is clarified.

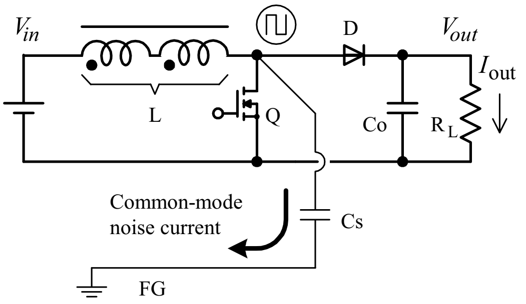
Key words: Balanced switching converter, common-mode conducted noise, noise cancellation, equally split winding inductor, parasitic capacitance.

1. Introduction

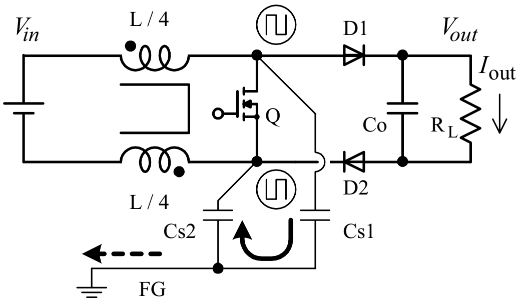
Common-mode conducted noise in switching converters frequently causes radiated noise emission from their power cord, so it is important to reduce this noise to meet EMC. Because conventional switching converters are usually using unbalanced circuit topologies, parasitic capacitance between the drain of an MOS-FET and the frame ground through its heat sink may generate the common-mode conducted noise.

We proposed a concept of balanced switching converter circuit, which is an effective way to reduce the common-mode conducted noise by current cancellation. As examples, a boost and a buck-boost converter versions of the balanced switching converter were presented and their effectiveness in the common-mode noise reduction was shown by experiments [1][2].

In this paper, the path of the noise current in a balanced boost converter circuit is investigated using a current probe. By measuring current waveforms and frequency spectra of the parasitic capacitances and the frame ground line, the mechanism of the common-mode noise reduction by current cancellation is clarified.



(a) Conventional unbalanced boost converter



(b) Proposed balanced boost converter

Fig. 1. Common-mode noise reduction by balanced boost converter [1].

2. Balanced Boost Converter Circuit [1]

Figure 1 (a) shows a conventional unbalanced boost converter circuit. A heat sink is usually used with the MOS-FET Q, so the parasitic capacitance Cs is formed between the drain of the MOS-FET and the frame ground FG through its heat sink. In the case where a small size and a low profile are strongly required to the converter, the metal frame ground itself may be used as a heat sink, so that Cs becomes very large. Because the drain voltage changes very rapidly in the switching time, a large current pulse flows through the parasitic capacitance Cs. Consequently this causes the large common-mode noise current to lead to serious problems.

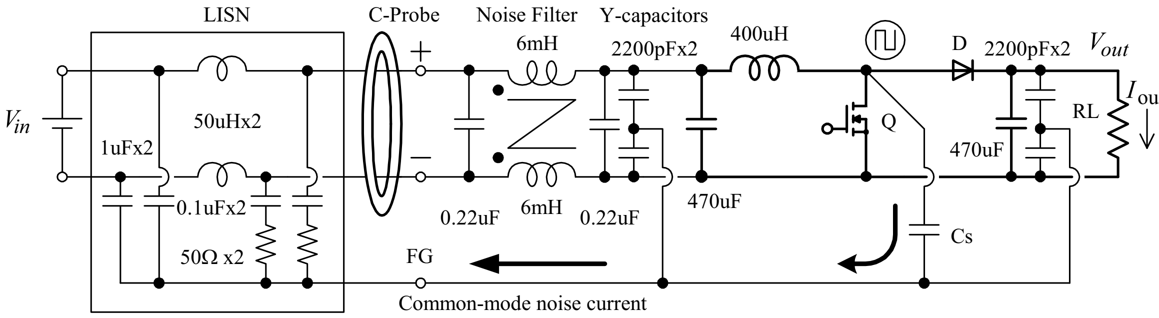
In order to solve this problem, we proposed a balanced switching converter circuit as shown in Fig. 1 (b). Its basic circuit operation is essentially the same as that of the conventional unbalanced boost converter. The winding of the inductor is equally split into two parts, thus the total winding turns are the same as those of the conventional unbalanced boost converter. In the balanced boost converter, the drain voltage and the source voltage of the MOS-FET Q change complementarily, that is, by the same amount but in an opposite polarity in the switching time. This is ideally performed by the equally split winding inductor. As a result, the common-mode conducted noise is much reduced by this balanced circuit topology.

In the case where the parasitic capacitances Cs1 and Cs2 are not exactly the same, an auxiliary capacitance can be added to equalize their values and to cancel their noise currents. Actually, the parasitic capacitance between the cathode of D2 and the frame ground can be used as a part of Cs2.

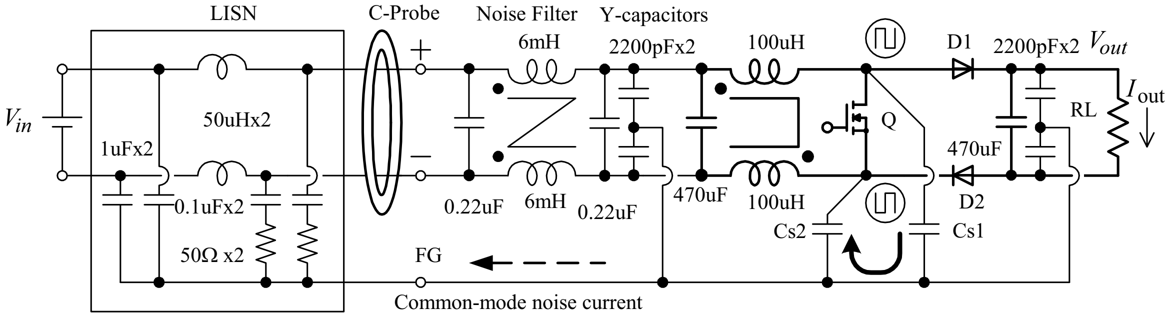
3. Experimental Confirmation of Common-Mode Noise Reduction

In order to confirm an intrinsic advantagen in the noise characteristics of the balanced converter, we made two kinds of boost converter circuits as shown in Fig. 2, where (a) is the conventional unbalanced converter and (b) is the proposed balanced converter. We used a LISN (Line Impedance Stabilizing Network) to standardize the input impedance seen from the converter input. A high-frequency current probe (C-Probe) is used to sense the common-mode noise current, which is measured by a spectrum analyzer.

Figure 3 shows comparison of experimental results between the conventional unbalanced boost converter (a) and the proposed balanced boost converter (b). Noise levels are converted to the voltage across an

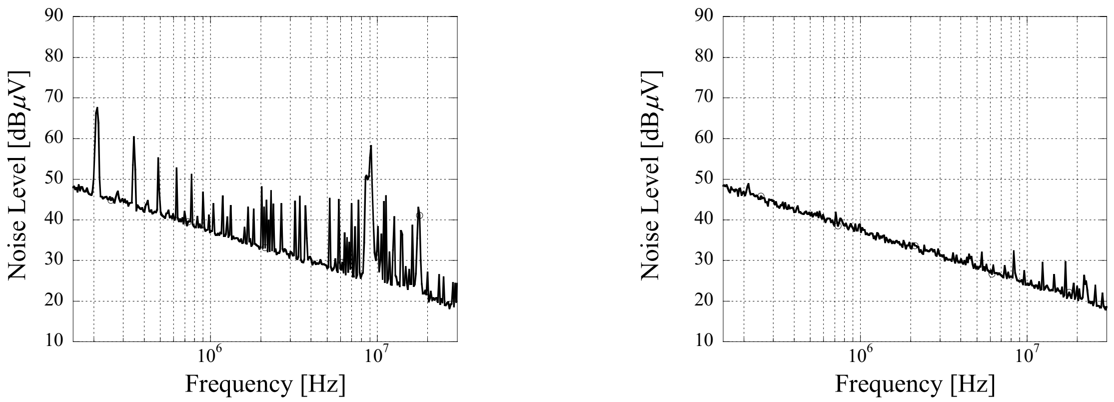


(a) Conventional unbalanced boost converter



(b) Proposed balanced boost converter

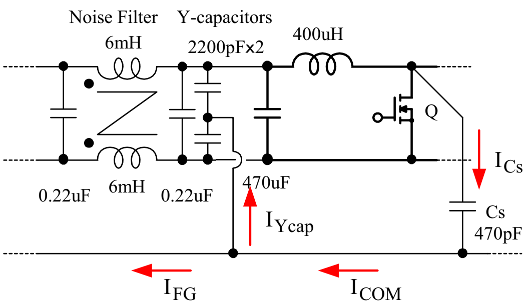
Fig. 2. Experimental circuits for common-mode noise current measurement. Conditions: $fs = 100$kHz, $D = 0.5$, Vin =30V, $Vout$ =60V, $Iout$ = 1A.
(A high frequency current probe (C-Probe) was used to sense the common-mode noise current.)



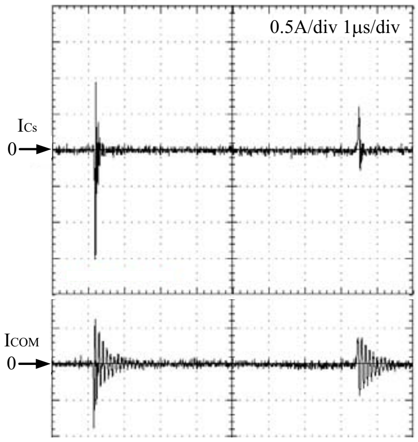
(a) Conventional unbalanced boost converter (Cs=470pF)

(b) Proposed balanced boost converter (Cs1=Cs2=470pF)

Fig. 3. Comparison of experimental results between the conventional unbalanced boost converter and the proposed balanced boost converter. Noise levels are converted to the voltage across an equivalent terminator of 25 ohms. (Frequency range:150kHz-30MHz)

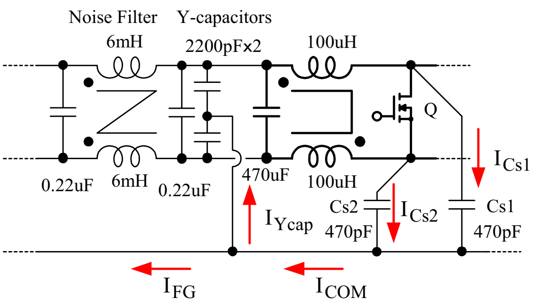


(a) Path of the noise current

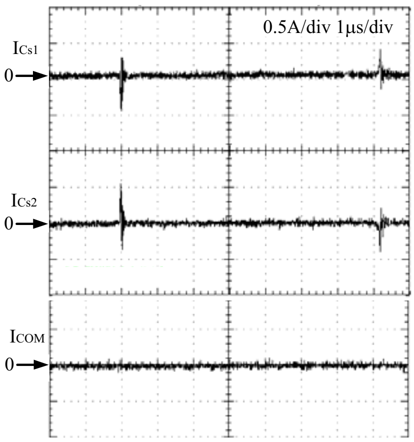


(b) Noise current waveforms

Fig. 4. Path and waveforms of noise current in the conventional unbalanced boost converter.



(a) Path of the noise current



(b) Noise current waveforms

Fig. 5. Path and waveforms of noise current in the proposed balanced boost converter.

equivalent terminator of 25 ohms. From these two figures, it is found that the common-mode conducted noise is much reduced in the balanced converter.

4. Mechanism of Common-Mode Noise Reduction

In order to clarify the mechanism of common-mode noise reduction, we investigate the path of the noise current using a current probe. Figure 4 shows the path and waveforms of noise current for the conventional unbalanced boost converter, and Fig. 5 shows them for the proposed balanced boost converter. In the case of the conventional unbalanced converter (Fig. 4), due to a rapid voltage change in the parasitic capacitance Cs, its current I_{Cs} flows into the frame ground as I_{COM}. This is a cause of the common-mode noise current. On the other hand, in the case of the proposed balanced converter (Fig. 5), the current of Cs1 (=I_{Cs1}) and the current of Cs2 (=I_{Cs2}) cancel each other, so very little common-mode noise current flows into the frame ground as I_{COM}.

Figure 6 shows the frequency spectra of noise current for the conventional unbalanced boost converter, and Fig. 7 shows them for the proposed balanced boost converter. In the case of the conventional unbalanced converter (Fig. 6), the current I_{C2} goes directly into I_{COM}, and its large portion is shunted to I_{Ycap}. The rest goes back through the frame ground as I_{FG}. On the other hand, in the case of the proposed balanced converter (Fig. 7), because I_{Cs1} and I_{Cs2} cancel each other, I_{COM} shown in Fig. 7 (b) becomes very small compared with Fig. 6 (b). This cancellation brings about the noise reduction in I_{FG} consequently.

As summarized, the mechanism of the common-mode noise reduction in the balanced boost converter is shown in Fig. 8 using equivalent circuits.

5. Conclusion

The path of the noise current in a balanced boost converter circuit has been investigated. By measuring current waveforms and frequency spectra of the parasitic capacitances and the frame ground line, the mechanism of the common-mode noise reduction by current cancellation has been well clarified.

References

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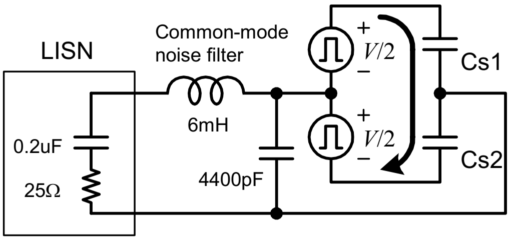
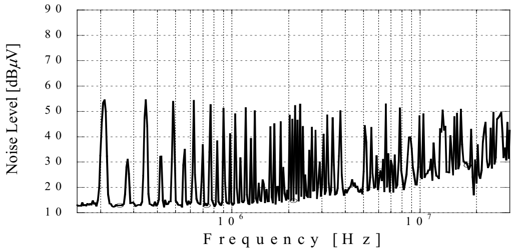
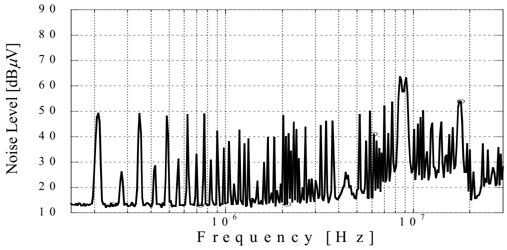


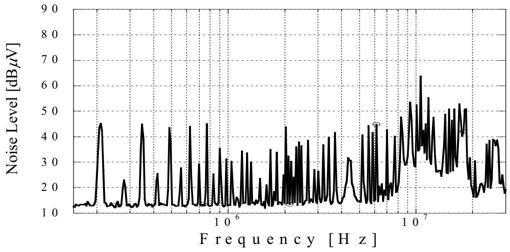
Fig. 8. Equivalent circuits to show the mechanism of common-mode noise reduction in the balanced boost converter.



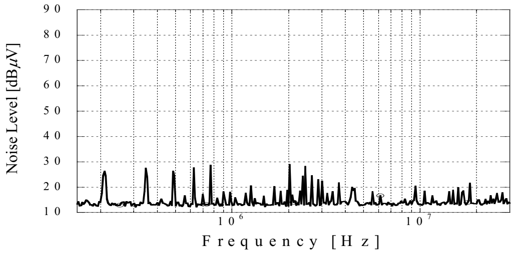
(a) Frequency spectrum of I_{Cs}



(b) Frequency spectrum of I_{COM}

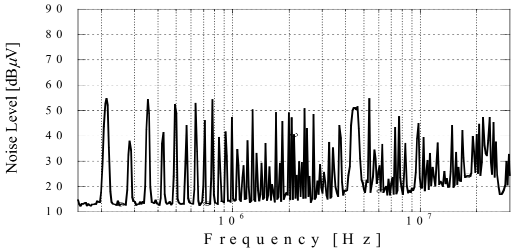


(c) Frequency spectrum of I_{Ycap}

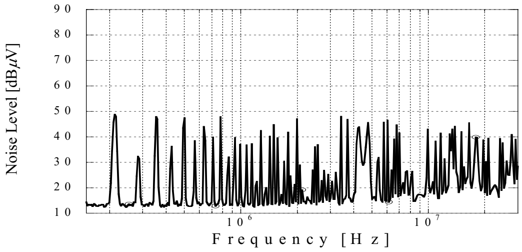


(d) Frequency spectrum of I_{FG}

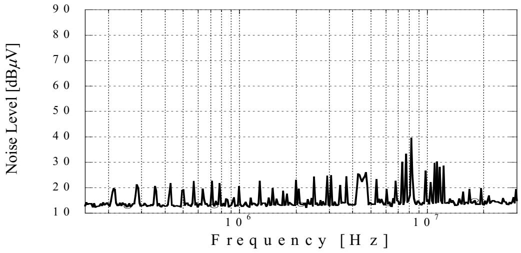
Fig. 6. Frequency spectra of noise current in the conventional unbalanced boost converter.



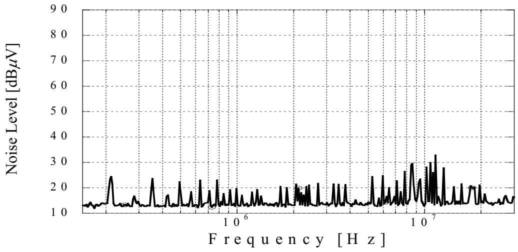
(a) Frequency spectrum of I_{Cs1}



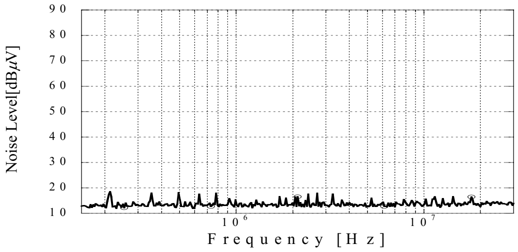
(b) Frequency spectrum of I_{Cs2}



(c) Frequency spectrum of I_{COM}



(d) Frequency spectrum of I_{Ycap}



(e) Frequency spectrum of I_{FG}

Fig. 7. Frequency spectra of noise current in the proposed balanced boost converter.