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Balanced Buck-Boost Switching Converter to Reduce Common-Mode Conducted Noise

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ABSTRACT

Because conventional switching converters have been usually using unbalanced circuit topologies, parasitic capacitance between the drain/collector of an active switch and the frame ground through its heat sink may generate the common-mode conducted noise. We have proposed a balanced switching converter circuit, which is an effective way to reduce the common-mode conducted noise. As an example, a boost converter version of the balanced switching converter was presented and the mechanism of the common-mode noise reduction was explained using equivalent circuits. This paper extends the concept of the balanced switching converter circuit and presents a buck-boost converter version of the balanced switching converter. The feature of common-mode noise reduction is confirmed by experimental results and the mechanism of the common-mode noise reduction is explained using equivalent circuits.

Key Words: Common-mode conducted noise, Balanced circuit, Buck-boost switching converter

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 have been usually using unbalanced circuit topologies, parasitic capacitance between drain/collector of an active switch and the frame ground through its heat sink may generate the common-mode conducted noise. To cope with this problem an idea of using auxiliary anti-phase winding has been presented [1].

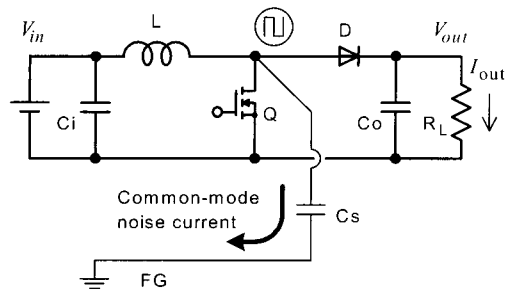
We have also proposed a balanced switching converter circuit, which is an alternative way to reduce the common-mode conducted noise.

As an example, a boost converter version of the balanced switching converter was presented and the mechanism of the common-mode noise reduction was explained using equivalent circuits [2].

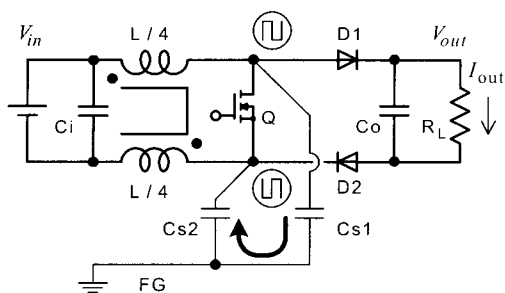
This paper extends the concept of the balanced switching converter circuit and presents a buck-boost converter version of the balanced switching converter. The feature of common-mode noise reduction is confirmed by experimental results and the mechanism of the common-mode noise reduction is explained using equivalent circuits.

2. Review of Balanced Boost Converter Circuit [2]

Fig. 1 (a) shows a conventional unbalanced boost converter circuit. This topology is often used as a PFC converter, where the MOS-FET Q switches a boosted high voltage of several hundred volts.



(a) Conventional unbalanced boost converter

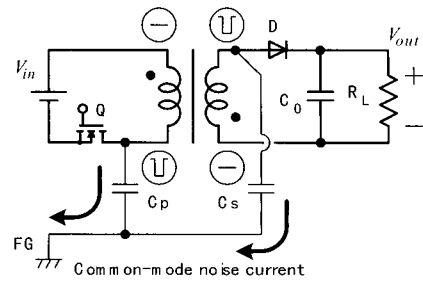


(b) Proposed balanced boost converter [2]

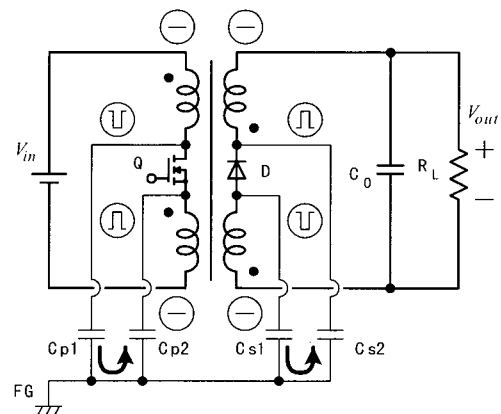
Fig. 1. Common-mode noise reduction by balanced boost converter.

A heat sink is usually used with the MOS-FET, so the parasitic capacitance C_s 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 C_s becomes very large. In the unbalanced boost converter, the source voltage of the MOS-FET is almost constant to the frame ground voltage level even in the switching time. On the other hand, the drain voltage changes very rapidly in the switching time, so a large current pulse flows through the parasitic capacitance C_s . 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



(a) Conventional unbalanced buck-boost converter



(b) Conventional unbalanced buck-boost converter

Fig. 2. Common-mode noise reduction by balanced buck-boost converter.

MOS-FET 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 C_{s1} and C_{s2} 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 C_{s2} .

3. Balanced Buck-Boost Converter Circuit

By extending the concept of the balanced switching converter circuit to a buck-boost converter, reduction in the common-mode conducted noise is realized. Two kinds of buck-boost converter topologies are compared in Fig. 2, where (a) is a conventional unbalanced converter and (b) is a proposed balanced converter.

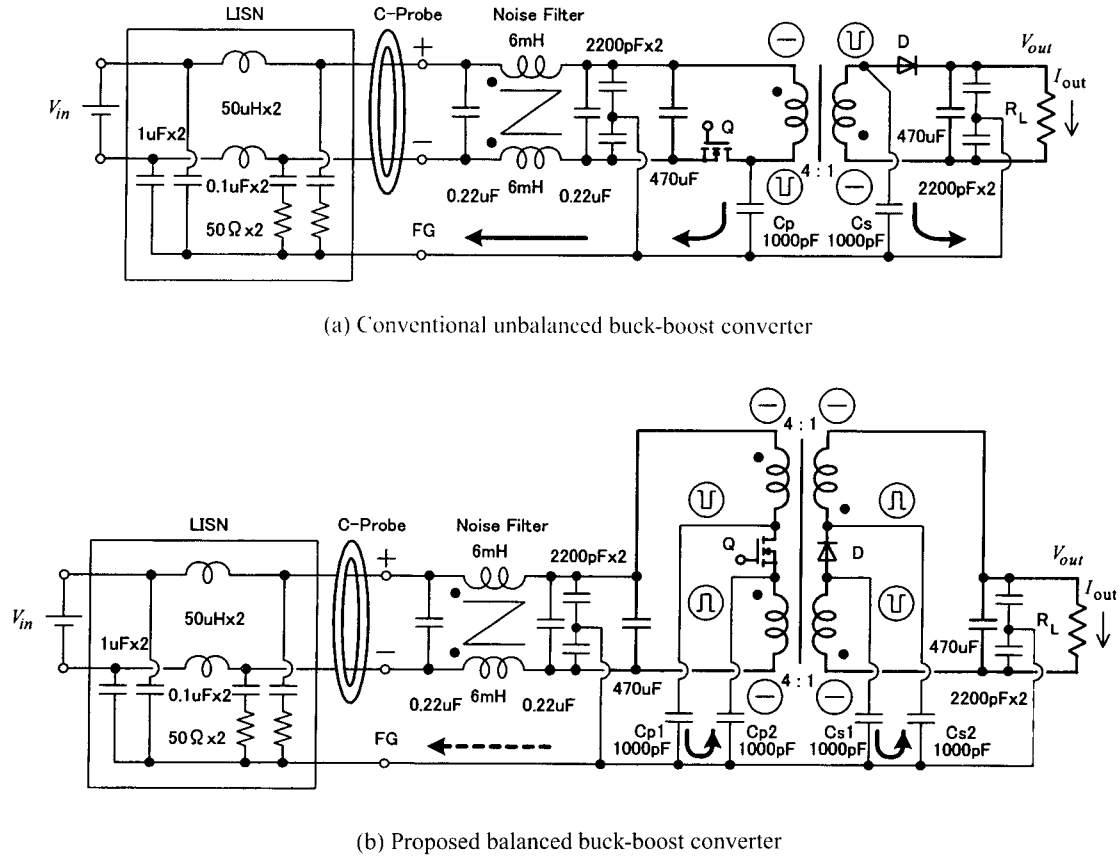


Fig. 3. Experimental circuits for common-mode noise current measurement. Conditions: $f_s = 100\text{kHz}$, $D = 0.3$, $V_{in} = 50\text{V}$, $V_{out} = 5\text{V}$, $I_{out} = 1\text{A}$. (A high frequency current probe (C-Probe) was used to sense the common-mode noise current.)

The basic circuit operation as a buck-boost converter is the same for these two topologies, but they are different in the common-mode noise generation. In the conventional buck-boost converter (a), the parasitic capacitance C_p between the drain of the main switch Q and the frame ground FG through its heat sink may generate the common-mode conducted noise to lead to serious problems. In addition, the parasitic capacitance C_s between the anode of the secondary diode D and the frame ground may also generate the common-mode conducted noise.

On the other hand, in the balanced buck-boost converter (b), the drain voltage and the source voltage of Q change by the same amount but in an opposite polarity in the switching time. This is ideally performed by the equally split primary winding. As a result, the common-mode conducted noise is reduced by this balanced circuit topology. In the case where the parasitic capacitances C_{p1} and C_{p2} are not the same value, an auxiliary capacitance

can be added to equalize their values and to cancel their noise currents.

In the secondary side of the transformer, the anode voltage and the cathode voltage of D change by the same amount but in an opposite polarity in the switching time. This is ideally performed by the equally split secondary winding. As a result, the common-mode conducted noise is reduced by this balanced circuit topology too. In the case where the parasitic capacitances C_{s1} and C_{s2} are not the same value, an auxiliary capacitance can be added to equalize their values and to cancel their noise currents.

4. Confirmation of Common-Mode Noise Reduction by Experiments

In order to confirm the noise characteristics of the balanced converter, we made two kinds of buck-boost converter circuits as shown in Fig. 3, where (a) is the conventional unbalanced converter and (b) is the proposed

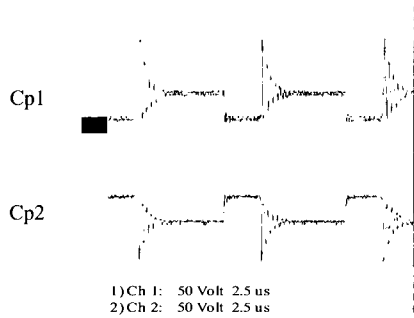


Fig. 4. Voltage waveforms of Cp1 (upper) and Cp2 (lower).

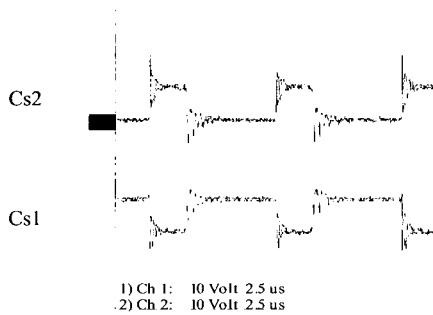
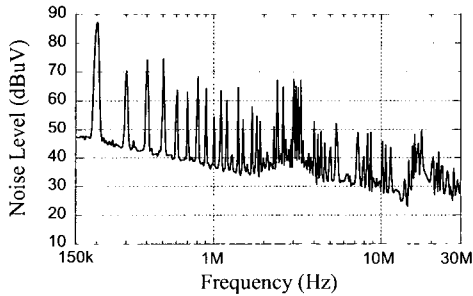
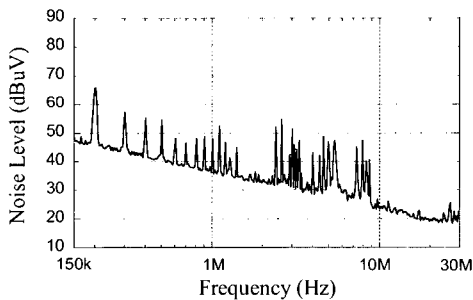


Fig. 5. Voltage waveforms of Cs2 (upper) and Cs1 (lower).



(a) Conventional unbalanced buck-boost converter



(b) Proposed balanced buck-boost converter

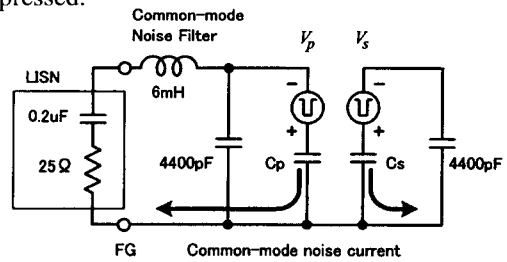
Fig. 6. Experimental results (150kHz-30MHz). The upper trace is for the conventional unbalanced converter and the lower trace is for the proposed balanced converter. Noise levels are converted to the voltage across an equivalent terminator of 25 ohms.

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.

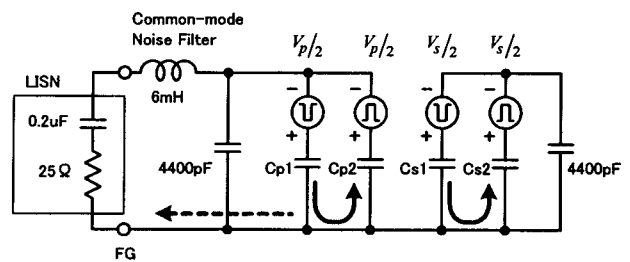
Fig. 4 illustrates that the drain voltage and the source voltage of Q change by the same amount but in an opposite polarity in the switching time. Fig. 5 illustrates that the anode voltage and the cathode voltage of D change by the same amount but in an opposite polarity in the switching time.

Fig. 6 shows experimental results, (a) is for the conventional unbalanced converter and (b) is for the proposed balanced converter. Comparing these two figures, it is found that the common-mode conducted noise is much reduced in the balanced converter.

In order to explain the advantage of the balanced converter, these two buck-boost converters are compared with their equivalent circuits in Fig. 7 from the viewpoint of the current path in the switching time. In the conventional unbalanced converter (a), the common-mode noise is generated by a rapid voltage change in the parasitic capacitance Cp and Cs. On the other hand, in the balanced converter (b), the current through Cp1 is absorbed by Cp2 and the current through Cs1 is absorbed by Cs2, and so the common-mode noise are well suppressed.



(a) Conventional unbalanced buck-boost converter



(b) Proposed balanced buck-boost converter

Fig. 7. Mechanism of common-mode noise reduction in the balanced buck-boost converter.

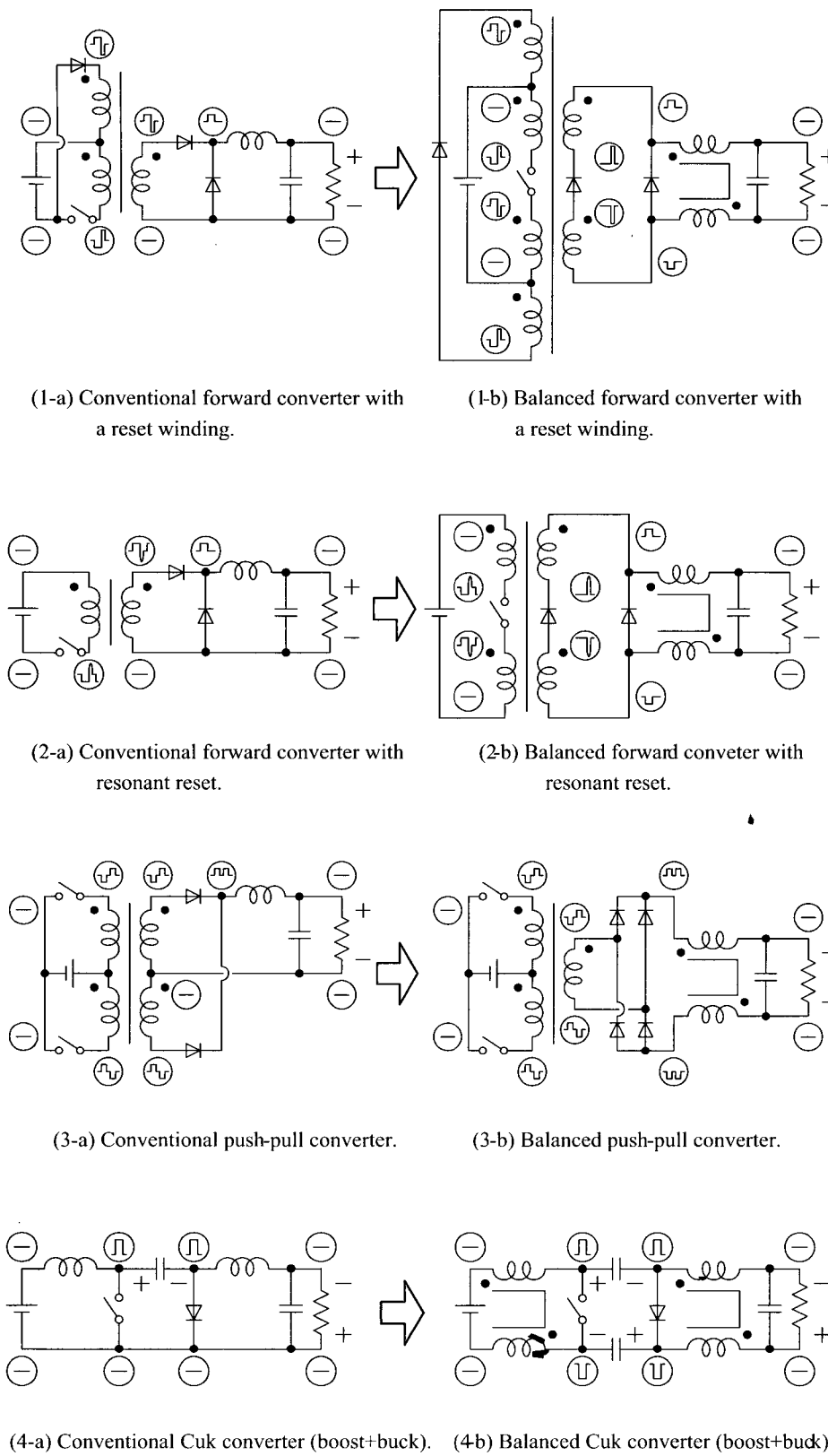


Fig. 8. Examples of conversion from conventional into balanced switching converters.

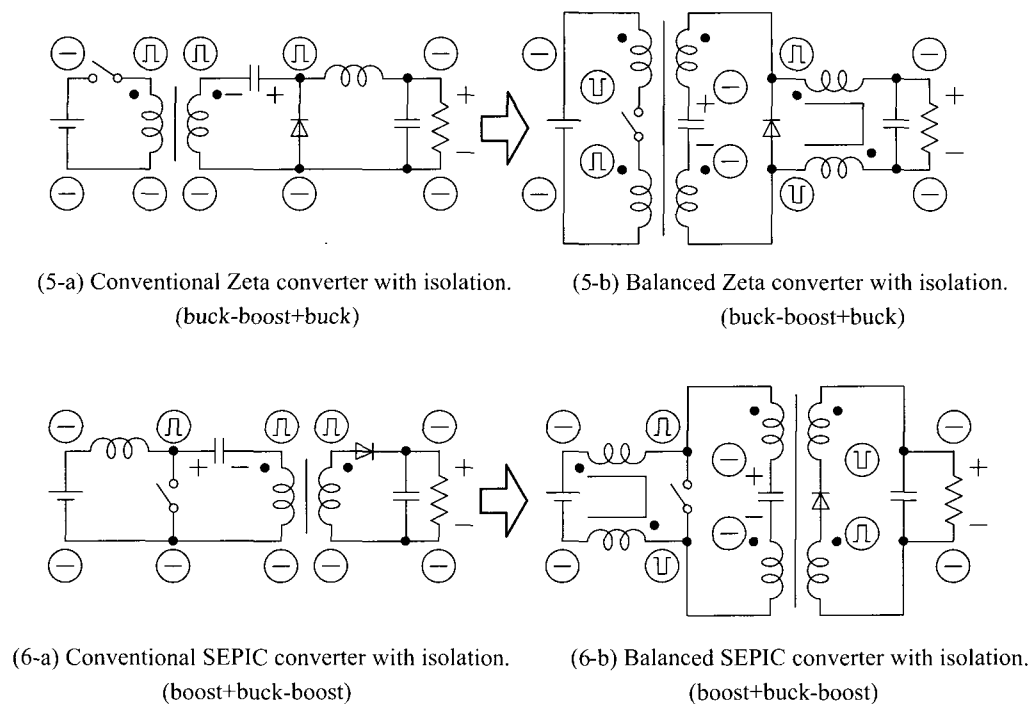


Fig. 8 (continue). Examples of conversion from conventional into balanced switching converters.

5. Application to Other Types of Switching Converter

The concept of the balanced switching converter is applied to some other types of switching converter as shown in Fig. 8. This concept can be applied to any switching converter topologies. Practically, such topologies with one active switch are desirable, because they do not suffer from a large common-mode noise current due to a slight difference in the timing of the plural active switches in the case where those plural active switches are supposed to operate simultaneously.

6. Conclusion

A buck-boost converter version of the balanced switching converter was presented and the mechanism of the common-mode noise reduction was explained using equivalent circuits. This good feature was confirmed by experimental results. The concept of the balanced switching converter was applied to some other types of switching converter. Detailed noise analysis will be presented in another paper.

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