Novel Techniques to Cancel Common-mode Noise Based on Noise Balance

Abstract:

Role of winding shielding on the parasitic capacitances of transformer and common-mode (CM) noise is analyzed in details when considering the effects of the secondary side noise source. Based on the proposed model of CM noise, two novel techniques to cancel CM noise by balancing noise is given; experiment results show CM noise is greatly reduced when the techniques are adopted.

Ⅰ. Introduction

A switching power converter generates larger CM noise as a result of the switching operations in the presence of parasitic capacitance between windings of transformer. In order to reduce common-mode EMI emission, a Faraday shielding between the primary and secondary windings of the transformer is often adopted in practice to reduce the effective coupling capacitance between the windings. Some researches on the modeling of the stray capacitive effects in the transformer were reported [1, 2, 3]. However, they usually did not consider the effects of the shielding and were not good enough for EMI analysis in practical design.

Typically, CM noise makes up a significant fraction of electromagnetic interference (EMI), so large size of CM choke is needed if we want to suppress EMI noise in the input line. In order to reduce the size of EMI filter and cost, noise cancellation techniques have been introduced to the area of EMI in resent years [4][5], Those techniques have the disadvantages of complexity and need additional components. In this paper, role of winding shielding on parasitic capacitance of transformer and CM noise when taking into account the effects of the secondary side noise source is analyzed in details; based on model of CM noise, two novel techniques to cancel CM noise by balancing noise are given, It is simpler or less cost compared with previous techniques, the techniques can be applied to isolated converters, such as Fly-back converter, Forward converter, etc. In the last section of the paper, effect of the method on CM noise reduction is verified by experiments.

Ⅱ. Principle of CM Noise Balance

Takes fly-back converter as an example, Fig.1 shows the flowing path of CM current when shielding is used in the transformer; V_p and V_s denote the EMI noise sources by the operations of primary MOSFET switch and secondary rectifier diode respectively. The *hot-voltage* point in primary is 2 and the *hot-voltage* point in secondary is 3, C_{ps} denotes the equivalent lumped capacitance between terminal 2 and 4, representing the capacitive effect of primary winding to the secondary, C_{psh} and C_{ssh} are introduced to represents the equivalent lumped capacitances of primary winding and secondary winding to the shielding respectively. C_{p0} represents the capacitive coupling of MOSFET to heat sink. Usually primary side voltage is higher than secondary side, so shielding foil and heat sink is connected to primary minus to reduce the effect of Cps, as in Fig.1. In this case, C_{psh} and C_{p0} have no contribution to the CM noise because displacement current flowing through it is circulating to noise source. If shielding foil is connected to secondary side minus (terminal 4 in Fig.1), then C_{psh} has contributions to CM noise but C_{ssh} has not, this case will not be discussed in the paper for it is only used when secondary side voltage is higher than primary side.

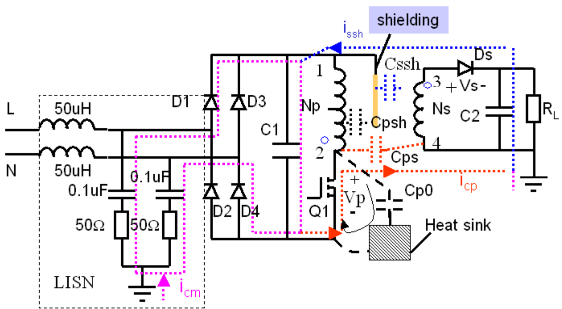

Fig.1. Coupling path of CM noise in Fly-back converter

Fig.2 shows the simplified model of CM noise for fly-back converter, i_{cp} and i_{ssh} are the current caused by primary side noise source V_p and secondary side noise source V_s respectively; i_{cm} is the current of CM noise. From the model, we know that,

$$i_{cm} = i_{cp} - i_{ssh} \qquad (1)$$

V_p and V_s has the same frequency but opposite phase, as the waveforms shown in Fig.3, therefore i_{cp} and i_{ssh} has the effect of counteraction with each other. Ideally, when equation (2) is met, then CM noise i_{cm} will be reduced to minimum.

$$V_p \cdot C_{ps} = V_s \cdot C_{ssh} \qquad (2)$$

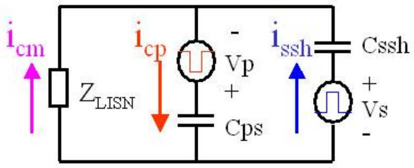

Fig.2. Model of CM noise

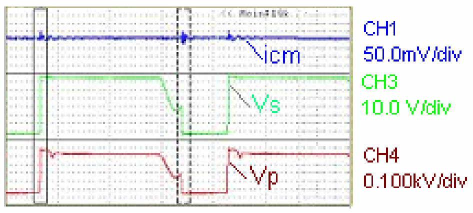

Fig.3. Waveforms of V_p, V_s and i_{cm}

Ⅲ. Methods to Cancel CM Noise

C_{ssh} is greatly larger than C_{ps} when Faraday shielding is used between primary winding and secondary winding. Therefore, i_{ssh} is usually larger than i_{cp} though V_p is higher than V_s in practical applications, and CM noise will be dominated by secondary noise i_{ssh}. In such cases, we can reduce CM noise by decrease C_{ssh} or increase C_{ps}, as following:

1. Optimal Design of shielding

For simplification, assume both primary winding and secondary winding of transformer are single-layer and a shielding is added between primary winding and secondary winding of the transformer.

A. Modulate the length of winding shielding

The art of modulating shielding length is shown in Fig.4. W is the window width of bobbin, θ is the central angle of the open area of the shielding, The length of the open area is:

$$x = \frac{1}{2} \cdot d \cdot \theta \ \text{ mm} \qquad (3)$$

and the length of shielding is:

$$l = \frac{1}{2} \cdot d \cdot (2\pi - \theta) \ \text{ mm} \qquad (4)$$

while $\quad x = \pi \cdot d - l \ \text{ mm} \qquad (5)$

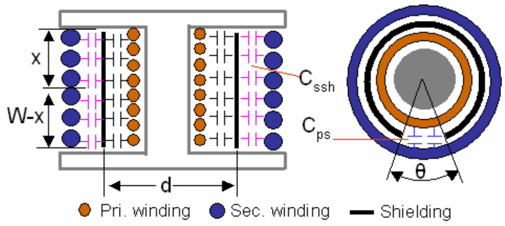

Fig.4. Sectional view of transformer and the art of modulating shielding length

Capacitive coupling effect of the open area between the primary winding and secondary winding can be equated to Cps; Capacitive coupling effect of the area between secondary winding to shielding can be equated to Cssh. Though Cps and Cssh are equivalent lumped capacitances, it is actually a distributed capacitance since voltage is distributed along the windings of the transformer when switch is operating, as shown in Fig5.and Fig.6. Therefore charge will distribute along winding surfaces of these two parts of area,

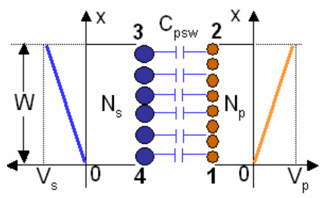

Fig.5. Voltage distribution and capacitive coupling in the open area

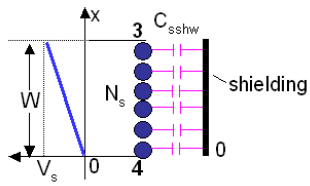

Fig.6. Voltage distribution and Capacitive coupling between Secondary winding and shielding

In the Fig.5 and Fig.6, Vp and Vs is supposed to linearly distribute along primary winding Np and secondary winding Ns respectively, surface of shielding can be considered as zero voltage potential. Cpsw is the capacitance per unit area of winding surface of the open area; Csshw is the capacitance per unit area of winding surface of the area between secondary winding and shielding. Both Cpsw and Csshw are 'static, volumetric' capacitances and can be calculate by analytical method [6]. According to the CM model in Fig.2 and the definition of Cps and Cssh, The total charge in the surface of open area is

$$V_p \cdot C_{ps} = \frac{C_{psw} \cdot W \cdot (V_p - V_S)}{2} \cdot x \qquad (6)$$

and

$$C_{ps} = \frac{C_{psw} \cdot W \cdot (V_p - V_S)}{2 \cdot V_p} \cdot x \qquad (7)$$

The total charge in the surface of the area between secondary winding and shielding is

$$V_s \cdot C_{ssh} = \frac{C_{sshw} \cdot W \cdot V_s}{2} \cdot l \qquad (8)$$

and

$$C_{ssh} = \frac{C_{sshw} \cdot W}{2} \cdot l \qquad (9)$$

To cancel CM noise, the optimal length of shielding Can be calculated when

$$V_p \cdot C_{ps} = V_s \cdot C_{ssh}$$

The position of the open area of shielding is not critical to the modulation effect because voltage of per turn winding is almost uniform. Fig.7 shows the rate of Cps and Cssh change along with x linearly. It indicates that the method will have good uniformity of canceling CM noise.

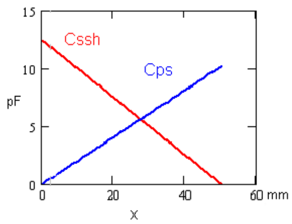

Fig.7. Effect of modulating shielding length

B. Modulate the width of winding shielding

Fig.8 represents the art of modulating shielding width. X represents the width of open area between the primary and secondary winding or the reduced width of shielding. With the increase of X, Cps will increase and Cssh will decrease. The optimal width of shielding can be obtained when

$$V_p \cdot C_{ps} = V_s \cdot C_{ssh}$$

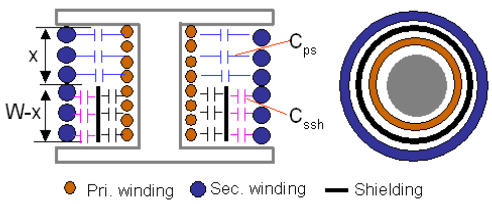

Fig.8. Sectional view of transformer and the art of modulating shielding width

Due to the voltage distribution along winding, different position of open area of the shielding makes different modulation effect. If position of open area is at the high voltage side of primary and secondary winding, Cps and Cssh will be very sensitive to the change of X, as shown in Fig.9, it indicates that uniformity of canceling CM noise is not good in such case.

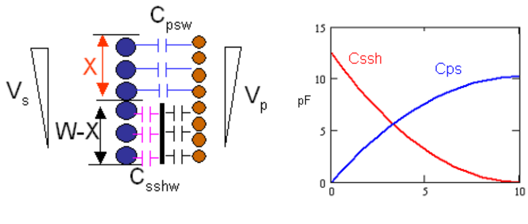

Fig.9. (a) Position of the open area of shielding at high voltage side winding; (b) effect of modulating shielding width

2. Adding a capacitance to balance noise

Another simple method to balance i_{ssh} and i_{cp} is to add a proper capacitance between terminal 2 and terminal 4 in Fig.1. The additional capacitance increase the effect of C_{ps} and i_{ssh}, so CM noise i_{cm} will be reduced to minimum if equation (2) is met.

In some applications, i_{cp} still is larger than i_{ssh} even though Faraday shielding is used, so the art of modulating shielding length or width is not effective, in such case, additional capacitance can be added between terminal 3 and terminal 1 in the Fig.1 to make i_{ssh} and i_{cp} balance.

Ⅳ. Application Example and Validation

A 65 *Watts* flyback power supply with 65 *kHz* operation frequency was used for experiment. Fig10 shows the winding structure and winding arrangement of the transformer. If shielding1 and shielding2 are traditional Faraday shielding, the shorted length of shielding1 and shielding2 will be 45mm and 56mm respectively. The optimal length of shielding was predicted by Calculation, result showed when the length of shielding2 was reduced to 26mm while shieldling1 uses Faraday shielding, Vp*Cps will be equal to Vs*Cssh, the CM noise will be reduced to its minimum.

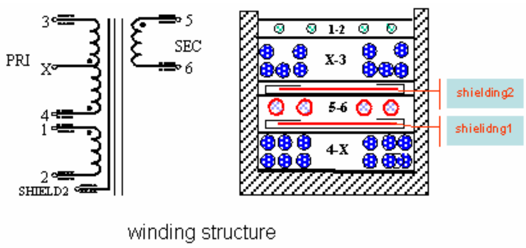

Fig.10. winding structure and winding arrangement of the transformer

Two transformers with different shielding were designed, The first transformer is designed with traditional Faraday shielding, shielding of the second transformer use predicted optimal length. When both transformers are tested in the same prototype without any filter, The CM noise of the second transformer is about 23dBuV lower in comparison with the first one. Fig.12 shows the test result.

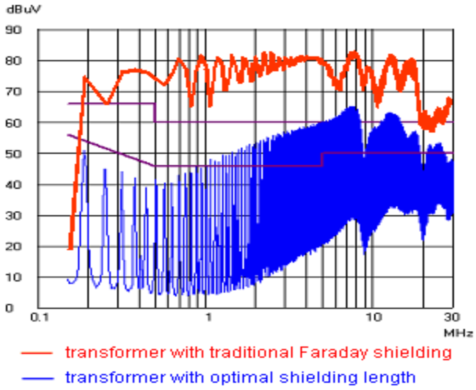

Fig.12. Tested CM noise of the two transformers

Ⅴ. Conclusions

An accurate model of CM noise and two novel techniques to cancel CM noise are introduced in the paper. Experiment results verified that:

1). The secondary side noise source has contribution to CM noise, particularly when output voltage is high. Its mechanism and effect on CM noise need to be considered when modeling CM noise.

2). Different connection of shielding makes different contribution of the secondary side noise source to CM noise. The proposed model of CM noise shows that the primary side and secondary side noise source have opposite effect on CM noise.

3). The art of modulating winding shielding of transformer or adding a compensate capacitance are the simple but effective methods to cancel CM noise, it will help to reduce the size of EMI filter.

Reference:

[1] *B. Cogitore, J.P. Keradec and J. Barbaroux,* "The two-winding transformer: an experimental method to obtain a wide frequency range equivalent circuit," IEEE Transactions on Instrumentation and Measurement, IM vol.43, pp. 364-371, Apr. 1994.

[2] *Qin Yu and Tomas W.Holmes*, "Study on Stray Capacitance Modeling of Inductors by Using the Finite Element Method," IEEE Transactions on Electromagnetic Compatibility, Vol.43, No.1, February 2001.

[3] *Hai Yan Lu, Jian Guo Zhu and Hui, S.Y.R.;* "Experimental determination of stray capacitances in high frequency transformers," IEEE Transactions on Power Electronics, vol.18, pp.1105 – 1112,Sept. 2003.

[4] *M.Shoyama, Masashi Ohba, and T.Ninomiya*, "Balanced buck-boost switching converter to reduce common-mode conducted noise," Power Electronics Specialists Conference 2002, pp.2056-2061.

[5] *Daniel Cochrane, Dan Y. Chen and Dushan Boroyevic*, "Passive Cancellation of Common-Mode Noise in Power Electronic Circuits," IEEE Transactions on Power Electronics, Vol.18, No.3, MAY 2003.

[6] *Antonio Massarini and Marian K. Kazimierczuk*, "Self-Capacitance of Inductors," IEEE Transactions on Power Electronics, Vol.12, No.4, JULY 1997.