Effective Switching Mode Power Supplies Common Mode Noise Cancellation Technique with Zero Equipotential Transformer Models

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Abstract—In this paper a transformer construction technique is proposed that effectively cut off the Common Mode (CM) noise voltage passing across the isolated primary and secondary windings. This technique employs the Zero Equipotential Line theory to construct an anti-phase winding. It effectively cuts down CM noise by eliminating the noise voltage across the isolated primary and secondary windings. The concept of maintaining an equipotential line along the bobbin and quiet node connections are justified by analysis. A well considered transformer design with the proposed CM noise cancellation technique can achieve high conversion efficiency as well as good CM noise insulation.

I. INTRODUCTION

Electromagnetic Interference (EMI) is always a barrier in designing a high efficiency Switching-Mode Power Supplies (SMPS) due to the presence of the common-mode (CM) noise. In many power supply designs, different noise suppression schemes are always required in order to meet the EMI requirements for electronic equipments, most of which create unwanted power loss that has lead to size, efficiency and thermal issues. Nowadays there are several commonly known methods to minimize the CM noise. Here is a brief summary of schemes on minimizing the CM noise flowing through the LISN and problems about these schemes.

1) Use of CM Noise Filters – This involves time-consuming designs as suggested by Shih [1], which commonly used in many SMPS designs. Usually, in order to gain satisfactory results, a bulky CM noise suppression filter is required. This is becoming more undesirable as the product size is shrinking and the filter actually lies on the power path. Damnjanovic et al [2][3] acknowledged that the importance of the size of the CM choke filters and proposed of SMD CM choke designs [4]. Although the size of the CM choke is small, the result is only effective from 1MHz or above, therefore the low frequency cannot be suppressed. The problem remains with use of large size CM choke to tackle the low frequency end up to 1MHz. Roc'h et al [5][6] also emphasized on the importance of the CM choke filter design because it is often difficult to design a low power loss, minimal size filter. An active CM filter is proposed by Mortensen [7] to try to further reduce the CM noise. Although this way the designer has greater flexibility to fine tune the CM filter than just use the passive component alone, the effect of such active filter is not easily modeled and the gain bandwidth is severely limited by the active component.

2) Minimize the parasitic coupling capacitors from the primary winding to the secondary winding – It leads to a high leakage inductance and produces efficiency problem.

3) Bypass Capacitor connected across the primary and the secondary side - Chen et al [8] have discussed on the effects of this Y-Capacitor on common mode noise performance, but the applicable capacitance is always limited by safety standards and this method alone usually cannot provide a low enough impedance to shunt all the CM noise current flowing along this path.

4) Faraday Shielding – The method requires careful integration of a piece of conducting sheet into the transformer to shunt away noise current. This is not always effective because there are many paths from which the CM noise current can go through. The shield must be properly installed in order to meet the safety requirement.

The CM noise source in SMPS is caused by the high frequency high voltage switching on the primary MOSFET. In the example of an isolated flyback converter, the CM noise current can be imagined to mainly follow two paths as shown in figure 1, via the parasitic capacitor from the drain node of the MOSFET to the ground, or via the isolation transformer coupling path to the secondary then through the parasitic capacitor to the ground.

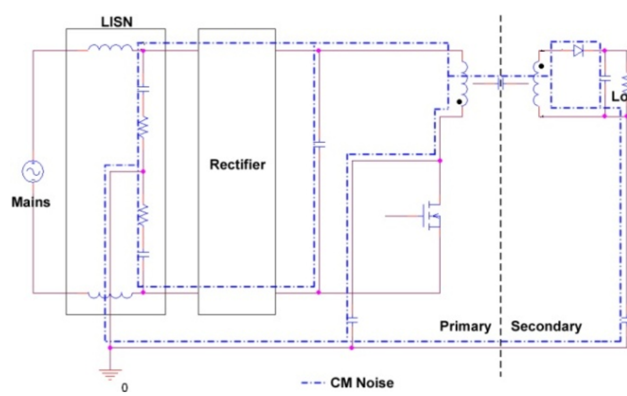


Fig.1. Flyback Converter showing CM noise paths

There are other techniques [9-15] that have been proposed to reduce the conducted CM noise in EMI. In the first noise path described, Cochrane et al [9] employed a compensation capacitor with an anti-phase winding to passively cancel the noise current flowing through the MOSFET parasitic capacitor. However, this simple addition of the capacitor cannot stop the significant part of noise current flowing through the secondary side and returned via the ground path. Herbert [10] proposed to use two or more transformers in series to reduce the overall parasitic capacitance between the primary and secondary windings so that it minimizes the coupling between them. This requires extra magnetic components and tedious designs. The reduction of the cross-coupling between the primary and secondary side is undesirable because this would increase the leakage inductance and lead to poor conversion efficiency in many cases. Wang [11] proposed another way of cancelling the CM noise by creating negative capacitances that balance the parasitic capacitances on different points in the power converter, yet it is not easy to generate repeatable results with another prototype.

In this paper, a new model is presented to construct the transformer which can effectively cut down the flow of CM noise. This method is based on the production of a balanced anti-phase noise voltage source [12][13] with a special transformer construction arrangements. An analytical model with P-Spice equivalent circuit is also presented to explain the theory of the method. This method produces no loss and requires no extra component, which is most favorable in terms of converter energy efficiency and small physical size.

II. EQUIPOTENTIAL LINE CONCEPT – ANTI-PHASE WINDING

The Equipotential Line concept for common mode noise reduction is introduced to cancel the noise current flowing from the primary winding to the secondary winding via the coupling capacitance C_{PS}. The idea is to produce an electric field opposite to that produced by the primary winding, it is possible to reduce the potential of the secondary winding to zero. In this case no common mode current can flow though the capacitance C_{PS}. The opposite electric field is produced by an additional anti-phase winding.

The flyback converter example in figure 1 is taken and an anti-phase winding with the same number of turns to the primary winding is added, as shown in figure 2. Since only the electric field of the anti-phase winding is required, one end does not connect to anything in order to avoid power current flow.

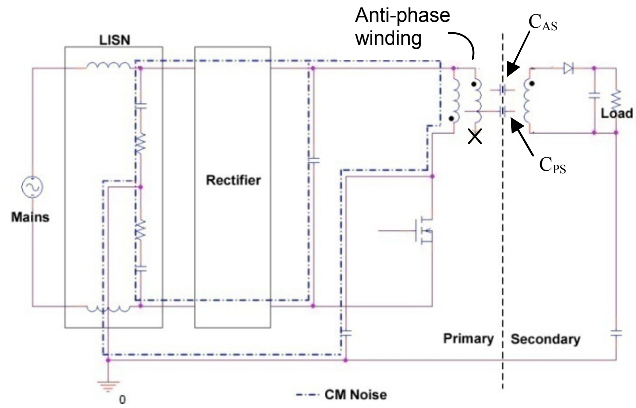
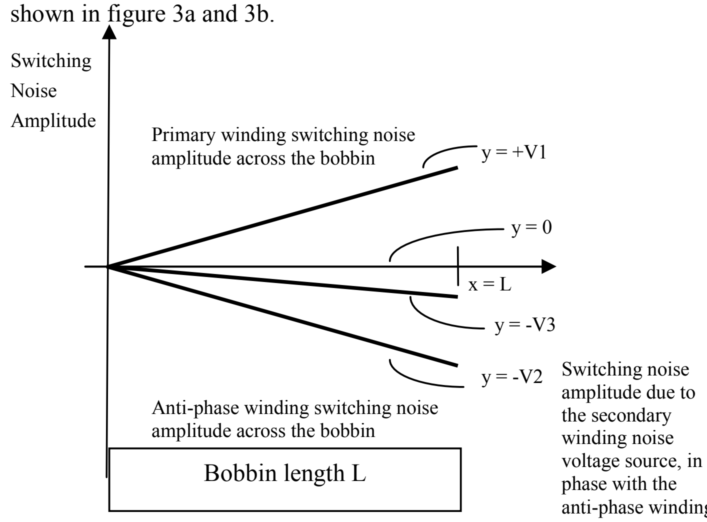


Fig.2. Flyback Converter with an anti-phase winding

Usually, the turns ratio N_{PS} between the primary and secondary winding is comparable, so the secondary winding will in fact be one of the noise voltage source as well, acting across the bobbin, similar to the anti-phase winding in the same phase because the switching action will also induce a switching voltage across the secondary winding, model is shown in figure 3a and 3b.



<u>Equivalent Circuit Model</u>
V1 = Switching noise source from the Primary Winding **P**
V2 = Switching noise source from the Secondary Winding **S**
V3 = Switching noise source from the Anti-Phase Winding **A**
C1 = C_{PS}
C2 = C_{PS} +C_{AS}
C3 = C_{AS}
Y = A bypass capacitor used for measurement purpose

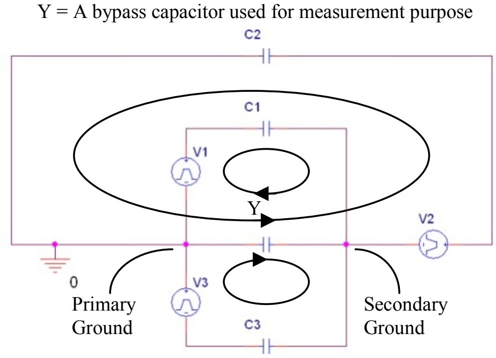


Fig.3a & 3b. A graph showing the noise amplitudes along the bobbin with the secondary noise source and an equivalent circuit model

$$V_P(C_1) - V_S(C_2) - V_A(C_3) = 0 \quad (1)$$

Where $V_P = N_{PS}(V_S) = N_{PA}(V_A)$

and $N_{PS} = \frac{N_P}{N_S}$ $\quad N_{PA} = \frac{N_P}{N_A}$

$\therefore V_P(C_1) - \frac{1}{N_{PS}} V_P(C_2) - \frac{1}{N_{PA}} V_P(C_3) = 0$

$\therefore C_1 = \frac{1}{N_{PS}} C_2 + \frac{1}{N_{PA}} C_3$

Now, $C_2 = C_1 + C_3$

$\therefore C_1 = \frac{1}{N_{PS}} (C_1 + C_3) + \frac{1}{N_{PA}} C_3$

$$\therefore \mathbf{C_{AS}} = \frac{(\mathbf{N_{PS}-1})}{(\frac{\mathbf{N_{PS}}}{\mathbf{N_{PA}}}+\mathbf{1})} \mathbf{C_{PS}} \quad (2)$$

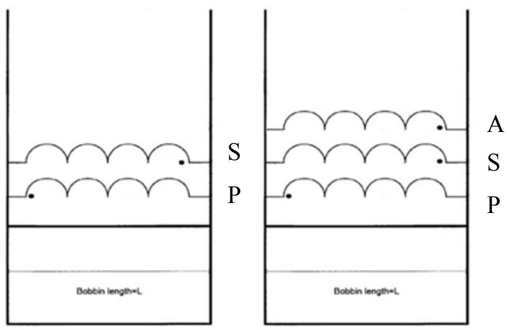


Fig 4a and 4b, winding constructions in a physical Transformer of a common flyback converter

III. EXPERIMENTS

A flyback converter is built as described in figure 1 & 2 to test the proposed method. The experiments concentrate on meeting the zero equipotential line along the bobbin. The switching frequency is 100kHz, input at 110 and 230Vac, output 25Vdc with 1.5A resistive load. Figure 4a and 4b show the transformer constructions in figure 1 & 2. The turns ratio is $N_{PS} = 3.92$. For a transformer with C_{PS} = 80pF @ 100kHz. Equation (2) suggested C_{AS} = 47.5pF @ 100kHz..

A conducted EMI test from 100kHz to 8MHz is performed and a RF current probe (HP 11967A) is employed to measure the noise current passing through the transformer primary – secondary coupling path. The setup is shown in figure 5. Three tests were performed for comparison.

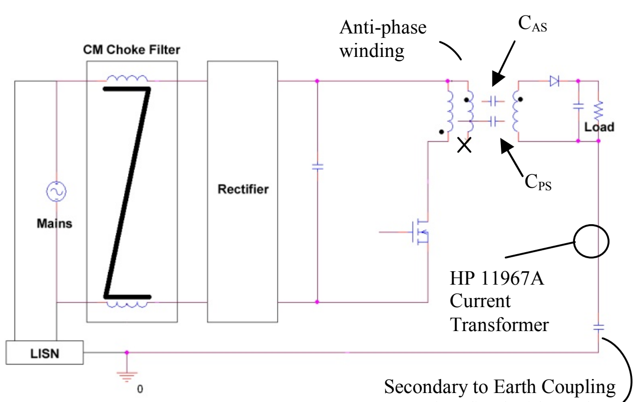


Fig.5. Conducted EMI setup for CM noise measurement with HP 11967A current transformer

In figure 6, trace 1 shows the original transformer performance as constructed in figure 4a with a 2mH CM choke filter, but without the anti-phase winding **A**. When the anti-phase winding **A** is employed as constructed in figure 4b, the Electro-Magnetic Interference (EMI) has dramatically improved by around 20dB at the low frequency end and effective up to 8MHz. The experimental result shows the theory proposed works effectively to reduce common mode noise.

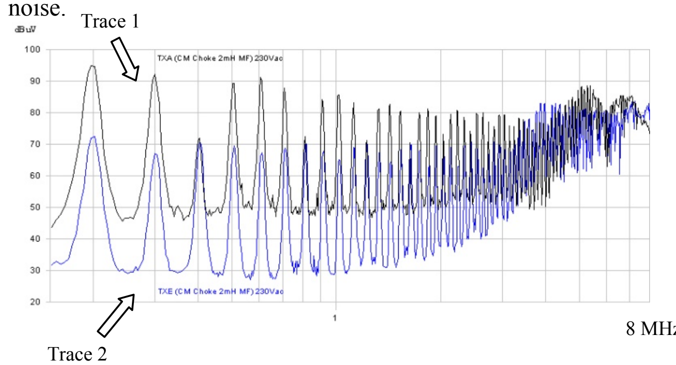


Fig.6 Conducted EMI tests showing different CM noise reduction

IV. CONCLUSION

In this paper a transformer construction technique is proposed. This technique employs the Zero Equipotential Line theory to construct an anti-phase winding. It effectively cuts down CM noise by eliminating the noise voltage across the isolated primary and secondary windings. The concept of maintaining an equipotential line along the bobbin and quiet node connections are justified by analysis. The anti-phase winding is very easy to design and it does not carry high current currents, this has definite advantage over the conventional CM noise filter. Experimental results proved the effectiveness of this method and common mode noise is reduced considerably. This method facilitates and provides a useful way to cancel the noise passing through the isolated transformer, confirmed by the conducted EMI tests. A well considered transformer design with the proposed CM noise cancellation technique can achieve high conversion efficiency as well as good noise immunization.

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