A study of integrated choke characteristic for EMI Filter Design

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Abstract

This paper studies the integrated choke characteristic for EMI filter design. Based on integrated choke performance, the insertion losses of the various kinds of integrated choke, compared with conventional common-mode choke with specific source and load impedances are investigated. The conducted EMI comparison among conventional common-mode choke, integrated common-mode choke and proposed integrated common-mode choke is verified by the experiment.

Keywords: EMI filter, common-mode choke, integrated magnetic, Insertion Loss

1. Introduction

EMI filter is generally used to reduce the conducted electromagnetic interference (EMI), differential mode and common mode emission, in switching power supplies. Theoretically, each component of EMI filter can mitigate either the differential mode or common mode emission. Normally, the EMI filter is composed of common mode capacitor (C_Y), differential mode capacitor (C_X), common mode choke (L_{CM}) and differential mode choke (L_{DM}). The common and differential mode choke of EMI filter are mainly used to limit the common mode and differential mode emission, respectively. The ferrite core is used to be common-mode choke and powder core is used to be differential-mode choke because of low core loss, magnetic stability and high permeability at high frequency [1-3]. However, the size and weight of EMI filter principally depend on the size of choke. Therefore, there are many researches pointed on integrated common mode and differential mode choke [4-6].

Finally, the performance, conducted EMI and insertion loss, of conventional common-mode choke (CM), integrated common-mode choke (ICM) and proposed integrated common-mode choke (PICM) are compared and verified by the experiment.

2. Integrated Choke

The common mode choke (Zorro or balun) as shown in Figure 1 is usually used to mitigate the common mode interference. In theoretical, the common mode choke has high impedance for common mode current and zero impedance for differential mode current. Although, in fact the common mode choke can reduce the common mode current, the leakage inductance of common mode choke also can reduce the differential-mode current. The leakage inductance is proportional to the gap between winding. The wide distance winding will get high leakage inductance and low differential mode current but the narrow distance winding is vice versa. Therefore, the common mode choke of EMI filter is wide distance winding.

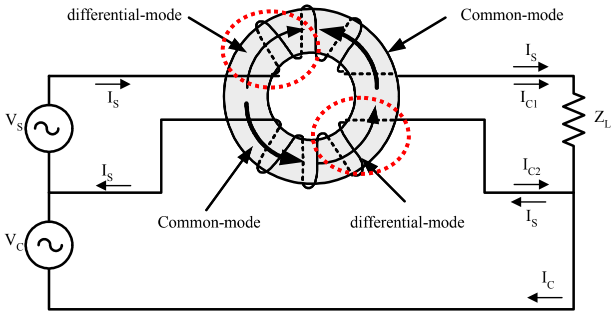


Figure 1 the flux direction of common-mode choke

Figure 2 shows the equivalent circuit of conventional common mode choke (CM). The direction of common mode current that passing through the common mode choke will strengthen the magnetic field intensity which affects to increase the inductance but the direction of differential mode current will generate the opposite direction of magnetic field intensity that means the result of zero inductance.

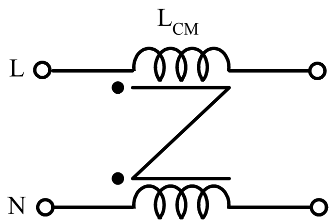


Figure 2 the equivalent circuit of conventional common mode choke (CM)

In 1992, Richard Frederick [4] claimed his invention for integrating the common mode and differential mode choke (ICM) as shown in Figure 3 which is added the differential mode core inside the common mode core and used the same winding of common mode winding either line or neutral winding. The advantage of this topology is to reduce the size and copper winding of EMI filter. However, the inside magnetic core or differential mode core still has space to add more winding for increasing the differential mode inductance.

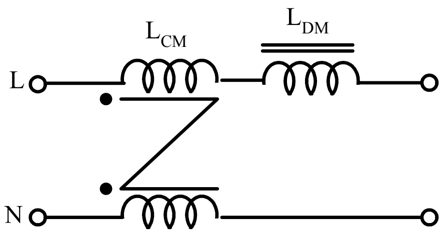


Figure 3 the equivalent circuit of integrated common mode choke (ICM) [4]

Figure 4 show the equivalent circuit of proposed integrated common-mode choke (PICM) [12]. The PICM can increase differential-mode inductance higher than of that ICM with the same dimension by adding another winding with inner core. This winding can generate the magnetic field intensity where its direction is the same direction of that the other inner winding.

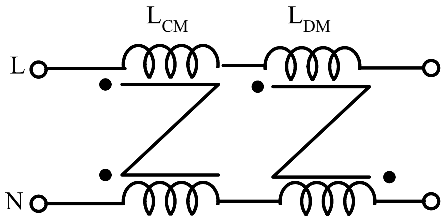
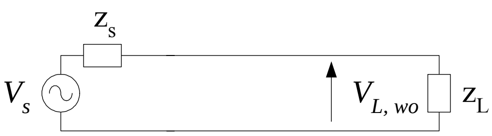


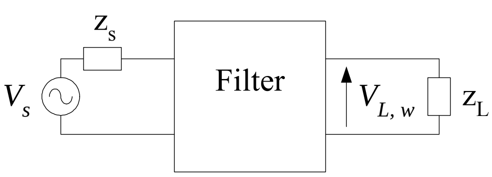
Figure 4 the equivalent circuit of proposed integrated common-mode choke (PICM) [12]

3. Insertion loss

The efficiency of noise reduction of EMI filter can be clearly determined in terms of insertion loss. Insertion loss is defined as the signal (voltage and current) reduction after insertion of a filter compared with the original signal value [2-3]. Figure 5 shows the definition of the insertion loss of filter.



(a)



(b)

Figure 5 the definition of the Insertion loss of filter
(a) load voltage without filter
(b) load voltage with filter

The insertion loss of the filter is defined as

$$IL = 10\log_{10}\left(\frac{P_{L,wo}}{P_{L,w}}\right) \quad (1)$$

$$= 10\log_{10}\left(\frac{V^2_{L,wo}/Z_L}{V^2_{L,w}/Z_L}\right) \quad (2)$$

$$= 20\log_{10}\left(\frac{V_{L,wo}}{V_{L,w}}\right) \quad (3)$$

where, $V_{L,wo}$ the output voltage of the signal source without filter

$V_{L,w}$ the output voltage of the signal source with filter

4. Experimental result

The test setup is shown in Figure 6. Line Impedance Stabilization Network (LISN) and EMI receiver are applied to measure the total conducted EMI. In this experiment, the common mode and differential mode emission are not separated. Figure 7 shows the layout and winding of CM, ICM and PICM chokes, respectively.

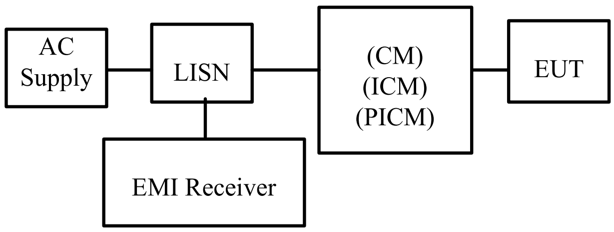
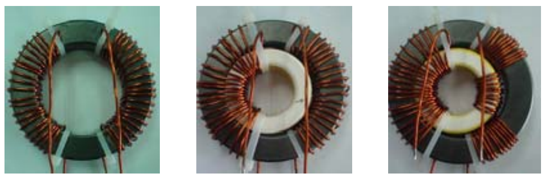


Figure 6 test setup of conducted EMI measurement



a) CM inductor b) ICM inductor c) PICM inductor

Figure 7 the structure of CM, ICM and PICM inductors

Noise source is generated by the operation of Ćuk converter for all experiments. The Ćuk converter, 100 W, is operated in discontinuous mode and opened loop control [11]. Table 1 and Table 2 show the specification of noise source and magnetic core for common mode choke, respectively.

Table 1 the Ćuk converter specification

Ćuk converter	Specification
Input voltage	24 VDC
Output voltage	48 VDC
Switching frequency	50 kHz

Table 2 the magnetic core specification

Magnetic Core	Specification
Material	H5C2
Initial permeability, μ_i	10000±30%
Saturation flux density B_s (mT) at 25 °C	400

Figure 8 shows the conducted EMI comparison of Ćuk converter among without choke and with three types of choke.

The CM, ICM and PICM chokes can decrease the conducted EMI between 1 MHz to 30 MHz. For the proposed integrated common-mode choke (PICM), it can reduce the conducted EMI about 5 dBμV between 2 MHz to 10 MHz when comparing with conventional common-mode choke and integrated common-mode choke and about 10 dBμV when comparing with no filter insertion. Figure 9 shows peak envelope of conducted EMI for four cases.

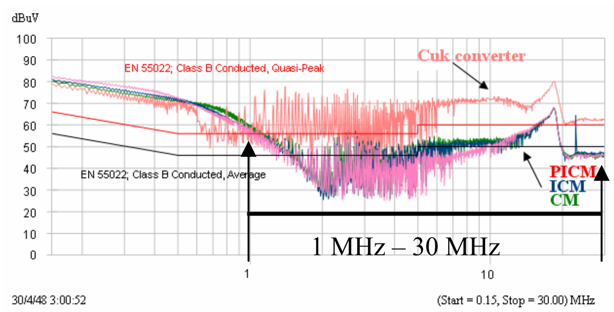


Figure 8 experimental result of conducted EMI

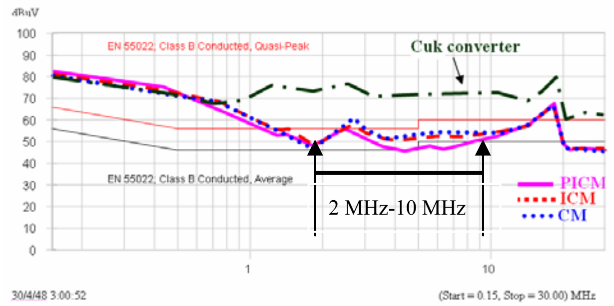


Figure 9 envelope of conducted EMI for four cases

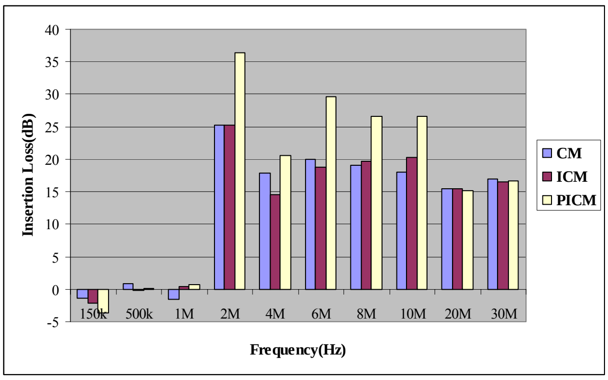


Figure 10 The Insertion loss of conducted EMI for three cases

Figure 10 shows the insertion loss comparison among CM, ICM and PICM chokes. The insertion loss calculation is shown in table 3-4. The insertion loss of PICM choke is higher than the others between 2 MHz to 10 MHz such as 11.1 dB greater than of that CM and ICM at 2 MHz. With the insertion loss calculation, it is quite agreement with the conducted EMI results as shown in figure 9.

6. Conclusions

The proposed integrated of common mode and differential mode choke (PICM) has insertion loss about 30 dB at frequency range 2 MHz to 10 MHz Furthermore, comparing with the convention common mode choke (CM) and integrated common mode choke (ICM), the PICM has higher insertion loss than of that about 10 dB at the frequency 2 MHz to 10 MHz. This techniques are done based on the constrain of choke dimension. However, the PICM has slightly insertion loss at frequency range about 150 kHz to 1 MHz and high frequency range about 20 MHz to 30 MHz, which is the effect of parasitic capacitance of each winding.

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Appendix

Insertion loss

Table 3 conducted EMI for four cases

f (Hz)	Cuk (dBuV)	CM (dBuV)	ICM (dBuV)	PICM (dBuV)
150k	78.9	80.3	81	82.5
500k	72.2	71.3	72.4	72.1
1M	58.5	60.1	58.1	57.8
2M	73.4	48.1	48.1	37
4M	65.1	47.2	50.6	44.5
6M	71.5	51.5	52.7	41.9
8M	72.2	53.1	52.5	45.6
10M	71.7	53.7	51.4	45.1
20M	63.5	48.1	48	48.3
30M	62.6	45.6	46.1	46

Table 4 insertion loss of conducted EMI for three cases

f (Hz)	IL (dB) CM	IL (dB) ICM	IL (dB) PICM	PICM-CM (dB)	PICM-ICM (dB)
150k	-1.4	-2.1	-3.6	-2.2	-1.5
500k	0.9	-0.2	0.1	-0.8	0.3
1M	-1.6	0.4	0.7	2.3	0.3
2M	25.3	25.3	36.4	11.1	11.1
4M	17.9	14.5	20.6	2.7	6.1
6M	20	18.8	29.6	9.6	10.8
8M	19.1	19.7	26.6	7.5	6.9
10M	18	20.3	26.6	8.6	6.3
20M	15.4	15.5	15.2	-0.2	-0.3
30M	17	16.5	16.6	-0.4	0.1

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