A New Technique of Integrated EMI Inductor Using Optimizing Inductor-volume Approach

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This paper presents the new technique of integrated EMI inductor using optimizing inductor-volume approach. The conducted EMI for proposed inductor is verified by the experiment. The experimental results show that the proposed integrated EMI inductor can reduce the conducted EMI comparing to the conventional common mode inductor about 10dBμV at frequency range 2 MHz-15 MHz. The conducted EMI experiment is verified by the operating of Ćuk converter.

Keywords : EMI Filter, Common mode choke, Integrated magnetic

1. Introduction

Switching power supplies and switching devices are advanced in high power rating and frequency range which can generate the conducted EMI. Therefore, the responsible of EMI filter is to decrease the conducted EMI. The main parts of EMI filter are composed of common-mode (CM) and differential-mode (DM) choke, common-mode and differential-mode capacitor. Ferrite core and powder core are selected to use in the EMI filter because of low core loss, magnetic stability and high permeability. However, the topology has never been changed. The disadvantage of EMI filter is to increase the size, weight and cost of electronic products. The differential-mode choke and common-mode chokes are generally separated the magnetic cores that means increasing the weight and size of EMI filter. Therefore, there are some patents which try to integrate the differential-mode and common-mode chokes to one magnetic core (2-4).

In this paper, the new technique of integrated EMI inductor using optimizing inductor-volume approach is proposed. The research is focused on the variation of winding length, weight, inductance values and self resonant frequency (SRF) of the choke.

2. The mode of propagation of conducted EMI

The mode of propagation of conducted EMI is divided in two modes: the common-mode interference and differential-mode interference.

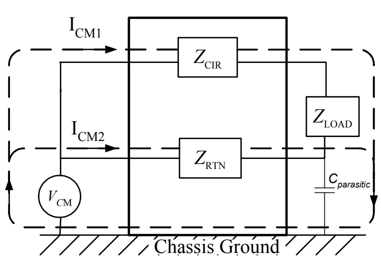
The definition of common-mode interference is the conducted EMI which is measured between the line and ground. Whereas, the differential-mode interference is measured between the lines or line and neutral. The common-mode voltage and differential-mode voltage of the single-phase system is shown in equations (1) and (2), respectively.

$$V_c = \frac{(V_{LG} + V_{NG})}{2} \tag{1}$$

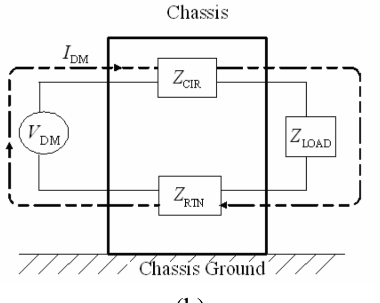
$$V_d = \frac{(V_{LG} - V_{NG})}{2} \tag{2}$$

where V_{LG} = The voltage between line and ground
V_{NG} = The voltage between neutral and ground
V_{LN} = The voltage between line and neutral

The direction of common-mode and differential-mode current of the single-phase system is defined in Figure 1 (a) and (b), respectively. The common-mode current passes through the parasitic capacitor of the circuit but the direction of differential-mode current is the same as the main current (6).



(a)



(b)

Figure 1. The direction of conducted EMI current (a) common-mode current and (b) differential-mode current.

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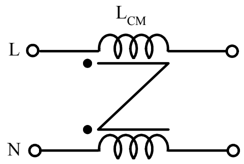
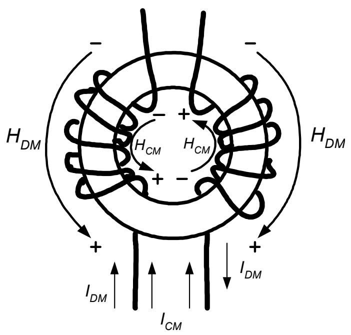
3. The common-mode and differential-mode choke

The common-mode choke (Zorro or balun) as shown in Figure 2 is normally 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 practically, 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. In general, the magnetic core of common-mode choke is ferrite core but the magnetic core of differential-mode choke is powder core (6-7).

Figures 2 (a) and (b) show the circuit of conventional common-mode choke and the direction of winding and magnetic field intensity of conventional common-mode choke, respectively. 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.



(a)

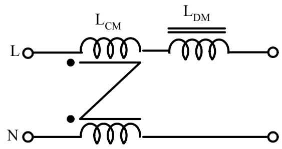


(b)

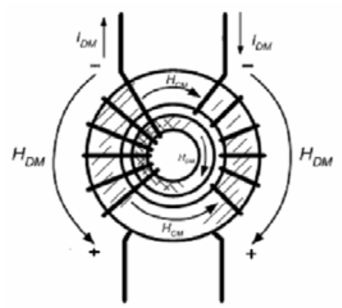
Figure 2. (a) The circuit of conventional common-mode choke. (b) The direction of winding and magnetic filed intensity of conventional common-mode choke.

The proposes of the integration technique of 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. However, the constrain of this topology should not to interrupt the heat transfer in the whole system.

This paper upgrades the common-mode choke of (2) using optimizing inductor-volume approach.



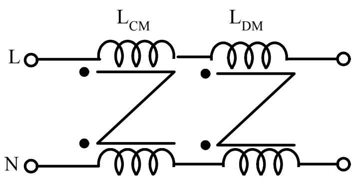
(a)



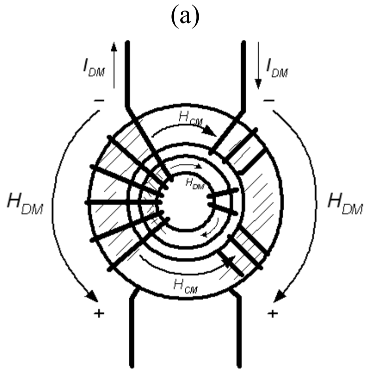
(b)

Figure 3. (a) The circuit of integrated common-mode choke (ICM). (b) The direction of winding and magnetic filed intensity of integrated common-mode choke.

Figures 4 (a) and (b) propose the new technique of integrated common-mode and differential-mode choke (PICM). 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.



(a)



(b)

Figure 4. (a) The circuit of proposed integrated common-mode choke (PICM). (b) The direction of winding and magnetic filed intensity of proposed integrated common-mode choke.

4. The experimental results

The ferrite core is used with the same specification for common-mode choke of CM, ICM and PICM. The number of turns equal to 20 turns for both sides. Additional, the ICM and PICM is used with the same powder core for differential-mode choke which has initial permeability (μ_i) equal to 75 (material # 26) (8). The PICM increases the number of turns for differential-mode choke equal to 10 turns which maximum turns can be winded. The copper winding is AWG # 18 and the distance between winding is fixed for all chokes. Figure 5 shows the layout and winding of CM, ICM and PICM chokes.

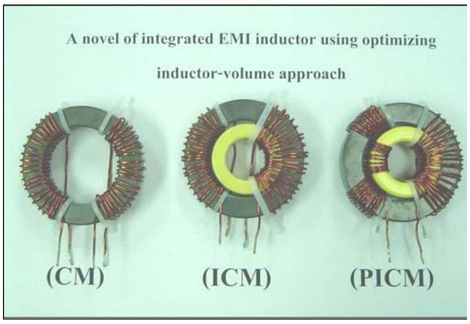


Figure 5. The structure of CM, ICM and PICM inductors

Table 1 shows the physical parameter of those inductors with the same volume. The weight of ICM and PICM is greater than of the conventional by 56 %. While the winding length of the ICM and PICM is greater than of the conventional by 8 % and 23 % respectively.

Table 1. The comparison of physical of parameters

	CM	ICM	PICM
Weight (g)	160	245	250
Winding length (cm)	260	280	320
Number of winding value	20:20	20:20	20:30
Inductance value (mH)	2.74:2.70	2.9:2.8	2.61:2.66

Noise source is tested using the operation of Ćuk converter for all experiments. The 100 W a Ćuk converter is operated in discontinuous mode and opened loop control. Table 2 shows the noise source specification.

Table 2. The Ćuk converter specifications

Ćuk converter	Specification
Input voltage	24 V_{DC}
Output voltage	48 V_{DC}
Switching frequency	50 kHz
Output current	2 A

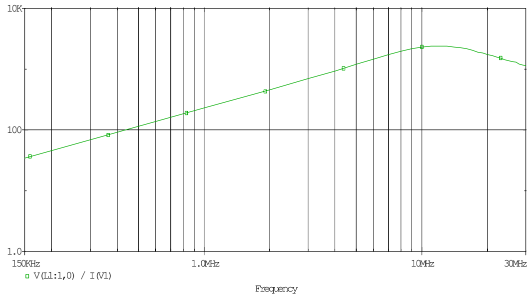


Figure 6. Simulated impedance response curve of Ćuk converter

Figure 6 shows simulation result of impedance-frequency curve of Ćuk converter. The SRF of the Ćuk converter is equal to 14.2 MHz (9). The resistive load is used for the Ćuk converter during conducted EMI measured. The test setup is shown in Figure 7. Line impedance stabilization network (LISN) is applied to measure the total conducted EMI. In this experiment, the CM and DM measurement are not separated.

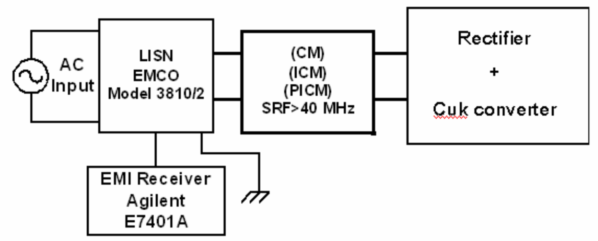


Figure 7. Test setup of conducted EMI measurement

5. The analysis of experimental result

To understand the noise phenomena form the Ćuk converter, the noise floor and the conducted EMI of the Ćuk converter, without any filters and chokes, measured as shown in Figure 8. The noise level is up to 60 dB at 150 kHz where the noise level at SRF of the Ćuk converter is 50 dB above the noise floor.

The experimental result of conducted EMI measured is shown in Figure 9. The limit line of CISPR 22 is used for benchmarking which cover frequency range from 150 kHz to 30 MHz. The experimental result shows that the PICM can reduce the conducted EMI about 10 dBμV lower than of that CM and 5 dBμV lower than of that ICM at 2 MHz – 15 MHz but other frequencies are quite similar. The EMI reduction at interval 2-15 MHz is confirmed the achievement of differential-mode reduction. In this work, there is no DM equipment in the laboratory to prove the DM EMI reduction. The Total EMI (CM+DM) is used in this research. However, the additional insertion loss of PICM depends on the permeability of powder core. At frequency around 15 MHz, the EMI is highest for all condition because it comes from the noise at the SRF of Ćuk converter. The self resonant frequency of those choke are inducted in the appendixes.

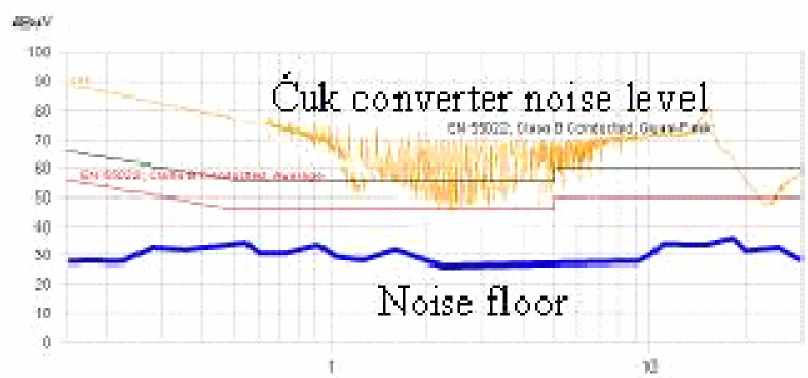


Figure 8. Experimental result of conducted EMI of Ćuk converter

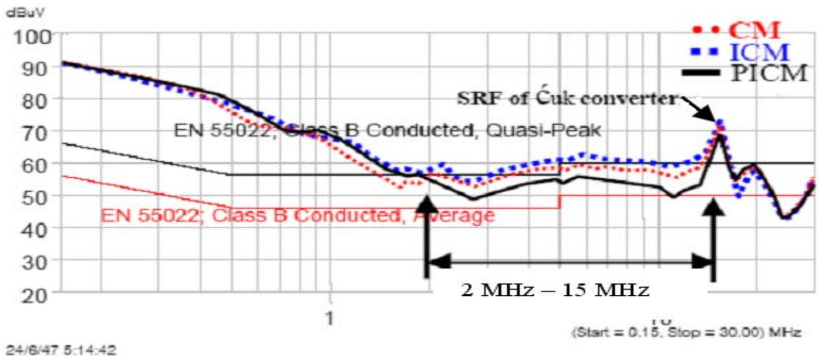


Figure 9. Experimental result of conducted EMI for three cases

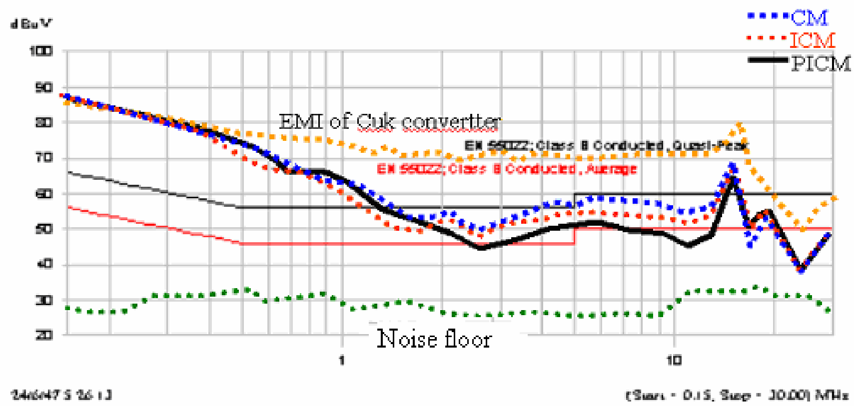


Figure 10. Experimental result of conducted EMI

Figure 10 shows experimental result of conducted EMI of Ćuk converter for three cases, the conducted EMI of Ćuk converter for without filter and the noise floor for without Ćuk converter. The common mode choke can decrease the self resonant frequency around 10 dBμV at 14.2 MHz when comparing without filter. The PICM is the best choke for this experiment. It can reduce the conducted EMI up to 25 dB comparing to noise level at 1 MHz to 10 MHz.

6. Conclusion

The proposed integration technique of common-mode and differential-mode choke (PICM) can reduce the conducted EMI about 10 dBμV at the frequency range 2 MHz – 15 MHz when comparing with the conventional common-mode choke (CM). This technique is done based on the constrain of choke volume. However, the advantage of PICM is slightly better than of that ICM. The addition of inner core and some winding the parasitic capacitance of each winding and the choke modeling should be studied as the further work.

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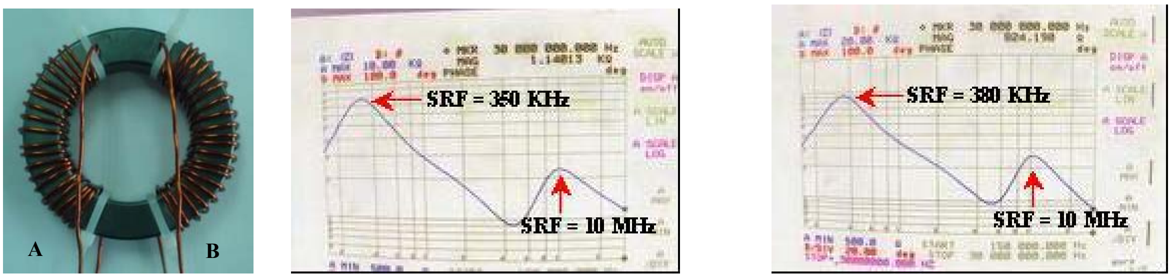
Appendix

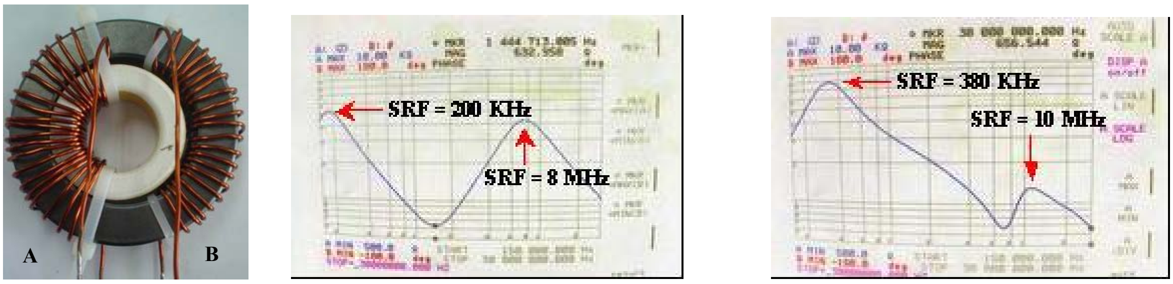
A. Conventional common mode choke (CM)



(a) (b) (c)

Figure 11. (a) The winding of conventional common mode choke (b) and (c) Self resonant frequency of conventional common mode choke of coil A and coil B, respectively.

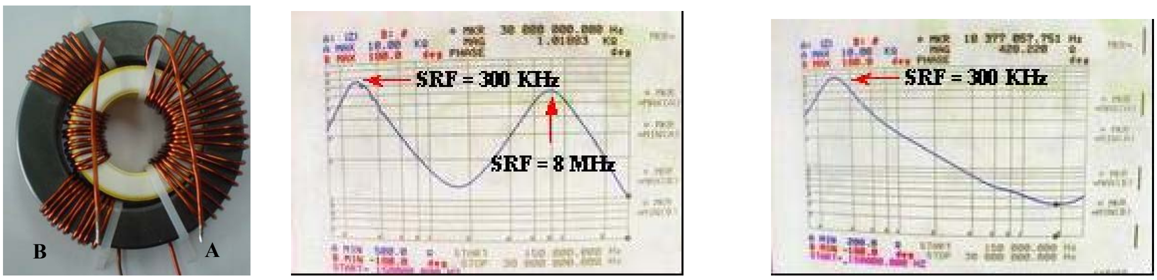
B. Integrated common-mode choke (ICM)



(a) (b) (c)

Figure 12. (a) The winding of integrated common mode choke (b) and (c) Self resonant frequency of integrated common mode choke of coil A and coil B, respectively.

C. proposed integrated common mode choke (PICM)



(a) (b) (c)

Figure 13. The winding of proposed integrated common mode choke (b) and (c) Self resonant frequency of proposed integrated common mode choke of coil A and coil B, respectively.

Where x-axis is Frequency (Hz)
y-axis is Impedance (Ω)