A Common Mode and Differential Mode Integrated EMI Filter

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***Abstract*— As the trend of Power electronics equipment is miniaturization and modularization, it is necessary to reduce the volume of each device in power electronics equipment. Traditional EMI filter, which has many devices, has become the major obstacle to reduce the volume power electronics equipment. Based on the worldwide research of integrated filter, a novel EMI integrated filter constructed with two different types of magnetic core is proposed. Equivalent wiring of Common Mode (CM) and Differential Mode (DM) current are analyzed. CM and DM equivalent circuit model are established. At last, the validity of the structure is certified by Saber software simulation and experiment.**

Keywords*—power electronics; EMI filter; integrated filter; Common Mode (CM); Differential Mode (DM)

I. INTRODUCTION

Switch-mode power supplies generate high electromagnetic inference (EMI) because of their fast switching action. Because EMI usually exceeds acceptable levels, the emission must be reduced. At present, in most practical cases, there are two ways to solve EMI problem in power electronics: one way is to find the EMI source in power electronics circuit and reduce or eliminate EMI by developing new device and designing new circuit topology. The other way is accomplished by using EMI filter to attenuate high frequency noise. And the second way is also the most common and effective method.

Because the trend of power electronics equipment is miniaturization and modularization, it is necessary to reduce the volume of each device in power electronics equipment. Traditional EMI filter, which has many devices, has become the major obstacle to reduce the volume power electronics equipment. At present, there are many kinds of integrated filter [2] [3] [4]. In literature [2], the integrated filter include one E type magnetic core and one I type magnetic core, two windings are placed in I type magnetic core. The advantages of this structure are that two windings can use one framework and CM and DM inductance value can be adjusted by regulating air-gap of E type magnetic core. But the magnetic core having air-gap affects the CM inductance value. Furthermore, the effective permeability would be reduced. In reference [3], the integrated filter is realized by two U type magnetic core of high permeability and one I type magnetic core of low permeability. The flaw of this structure is that the length of I type magnetic core is processed relatively accurate, besides, DM inductance is not easily adjusted. In reference [4], the I type magnetic core are transversely put on the window of the 口 type and 日 type magnetic core. The flaw of this structure is that CM and DM magnetic flux share largely common path, therefore which affect the CM inductance value.

In order to overcome above the flaws, this paper proposes a new structure, which is easily implemented, no air-gap in CM magnetic path, small influence between CM and DM inductance, and has favorable suppression EMI performance. This structure is come from reference [5].

II. PROPOSED STRUCTURE

The new integrated filter is realized by one big loop type magnetic core of high permeability and two small loop type magnetic cores of low permeability. Two small loop type magnetic cores are symmetrical transversely placed on big loop type magnetic core. The two identical windings are placed in big and small loop type magnetic cores. The new integrated filter's structure is shown in Fig.1.

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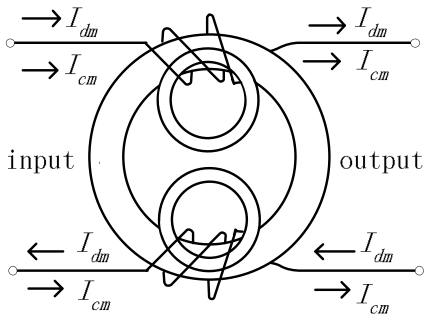

Figure1. A novel CM and DM integrated EMI filter

DM and CM current direction is illustrated in Fig.1. The big loop type magnetic core is to suppress CM noise. According to CM current direction and right-hand screw rule, the big loop magnetic core exhibits high impedance for CM signals but low impedance for DM signals. So the small loop type magnetic core is to suppress DM noise.

For integrated EMI filter, in CM and DM inductance's common path, superposition of CM and DM flux could reduce the effective permeability and CM inductance value. In reference [2] [3] [4], common magnetic path of CM and DM is very long which reduce the CM inductance value and seriously affects filtering performance of CM inductance. However, the new structure in this paper greatly reduces the common path of CM and DM magnetic flux, which improve the filtering performance especially for CM suppressing performance.

III. THEORY ANALYSES

Because of the different source and conducted path of CM noise and DM noise, CM and DM filter should be designed and analyzed respectively.

A. The theory analysis of CM filter

CM noise is come from between alternating current (AC) line (L.N) and ground (E). According to CM current direction, CM current equivalent wiring of this new CM and DM integrated EMI filter is shown in Fig.2. [6-7]

In Fig.2, because two windings are symmetrically placed in the big loop type magnetic core, N_1=N_2=N, L_1=L_2=L; N_1 and N_2 are the number of windings; $L_1$and L_2 are each winding inductance; $\Phi_1$andΦ_2 are flux; L_{AB} is the inductance between terminal A and B ; R is the magnetic resistance.

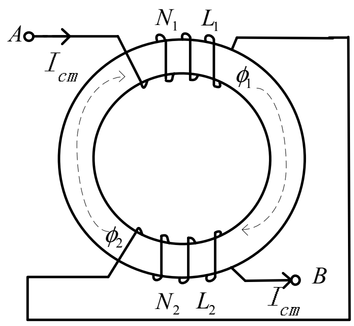

Figure2. Equivalent wiring of CM current

$$L = N^2/R \tag{1}$$

$$L_{AB} = \frac{\left(N_1+N_2\right)^2}{R} = \frac{\left(2N\right)^2}{R} = \frac{4N^2}{R} = 4L \tag{2}$$

But because of the existence of leakage inductance, in practices,

$$L_{AB} < 4L \tag{3}$$

From the reference [8], CM equivalent circuit is a LC low-pass filter, which is shown in Fig.3. L_{cm} is CM inductance, C_{cm} is CM capacitance.

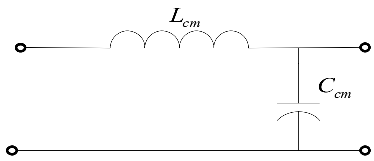

Figure3. CM equivalent circuit

$$L_{cm} = L_{AB} \tag{4}$$

$$C_{cm} = 2C_y \tag{5}$$

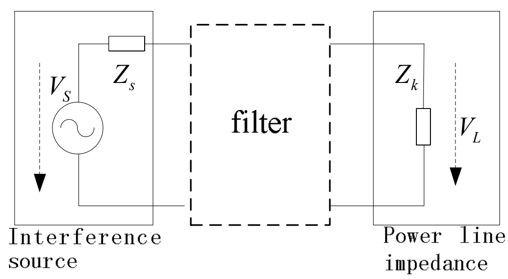

Figure4. Filter design equivalent circuit

$$\left|H(\omega)\right|_{LC} = \left|\frac{V_L}{V_S}\right| = \frac{1}{\omega^2 L_{AB} 2C_y} \tag{6}$$

Above equation is the approximate transfer function of

CM equivalent circuit at high frequency. Input and output impedance don't affect the CM filtering performance and performance will be much better if the devices' parameter turn bigger. But in fact, C_y has the relation with the leakage current, so C_y is not too big.

B. The theory analysis of DM filter

DM noise exists in between AC lines L and N. According to DM current direction, DM current equivalent wiring of this new CM and DM integrated EMI filter is shown in Fig.5.

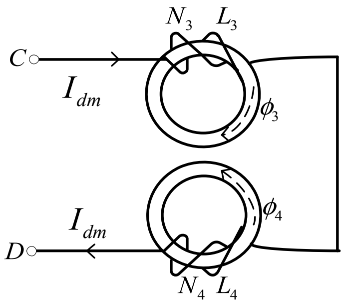

Figure5. Equivalent wiring of DM current

The two identical windings are feed through. Moreover, N_3=N_4=N, L_3=L_4=L_d; N_3 and N_4 are the number of windings; L_3 and L_4 are each winding inductance; Φ_3 and Φ_4 is flux; L_{CD} is the inductance between terminal *C* and *D*.

$$L_{CD} = L_3 + L_4 = 2L_d \tag{7}$$

But because of the existence of leakage inductance, in practices,

$$L_{CD} < 2\,L_d \tag{8}$$

DM equivalent circuit is a Π type filter, which is shown in Fig.6, L_{dm} is DM inductance, C_{dm} is DM capacitance.

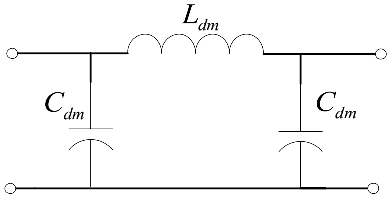

Figure6. DM equivalent circuit

$$C_{dm} = C_x \tag{9}$$

$$L_{dm} = L_{CD} \tag{10}$$

Equation (11) is the approximate transfer function of DM equivalent circuit at high frequency. Input impedance will influence DM filtering performance.

$$\left|H(\omega)\right|_{LC} = \left|\frac{V_L}{V_S}\right| = \frac{1}{\omega^3 C_x^{\,2} L_{CD} Z_S} \tag{11}$$

IV. RESULTS

A. Simulated results

Based on above analysis, CM and DM equivalent circuit will be simulated by Saber software. Parameter is given by : L_{cm}=1.8mF, C_{cm}= 3nF, L_{dm} = 52.5 μ F, C_{dm}=71nF。The Source and load impedance are 50Ω.1V AC small signal is applied to the input of the filter. The amplitude change of output signal of filter with the input signal frequency is analyzed. Simulated waveforms are shown in Fig.7 and 8.

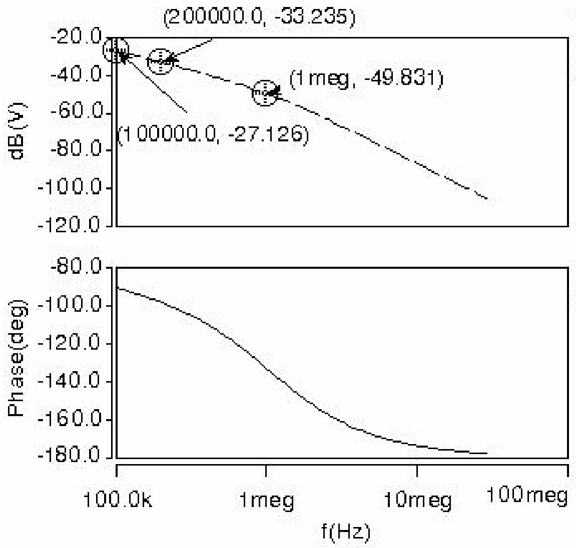

Figure7. Simulated output waveform of CM equivalent circuit

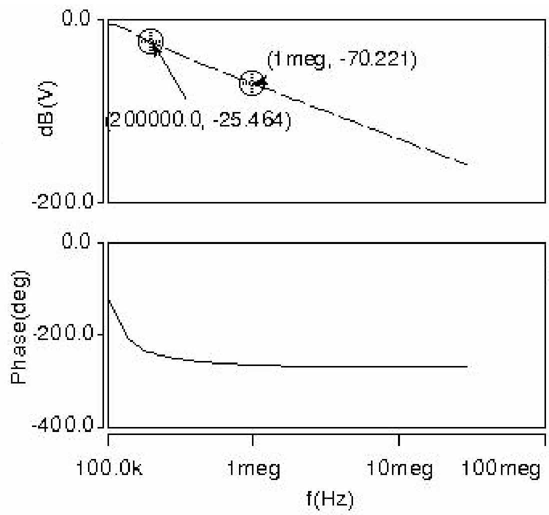

Figure8. Simulated output waveform of DM equivalent circuit

Seen from the simulated waveform, output amplitude is continually reduced when the frequency is becoming higher, and the curve is very smooth. But in fact, the measured curve would divert from the ideal curve because of the impacts of parasitic parameter on high frequency. The parasitic parameter is not in domain of this paper.

B. Experimental results [9-10]

In widely accepted practices, EMI filter can be evaluated by insertion loss (IL). A four-terminal network can represent EMI filter. Its insertion loss is expressed by the ratio of two powers or voltages.

$$IL=20\lg(U_1/U_2) \tag{12}$$

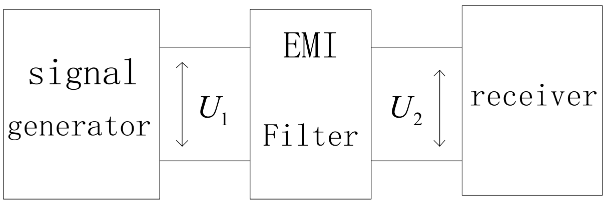

Figure9. Measurement of insertion loss of EMI filter

According to the definition of the insertion loss, designing of experiments is as followed: big loop type magnetic core is PHILIPS Company ferrite TX74/39/13, small loop type magnetic core is MICROMETALS Company ferrocart core T130-26. The 3.5V sine-wave signal is applied to input terminal of the new integrated filter. Output waveform is observed by oscilloscope. The waveforms are shown in Fig.10.

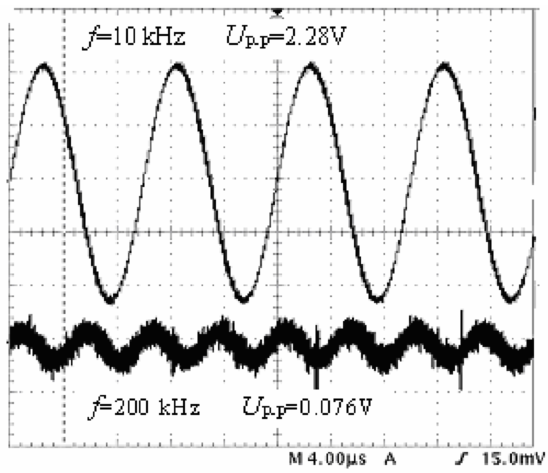

Figure10. (a) Measured output waveform of filter

f—frequency; U_{P-P}—peak-peak value of output

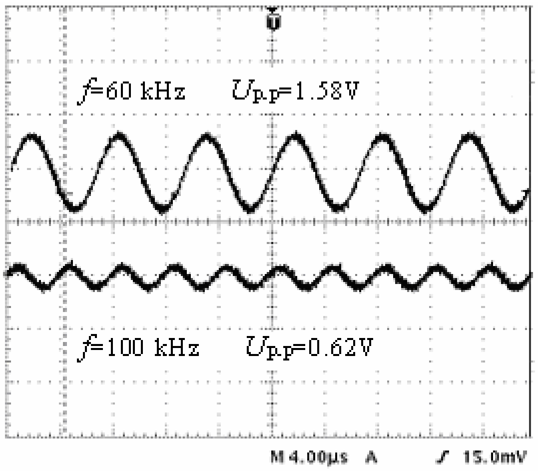

Figure10. (b) Measured output waveform of filter

f—frequency; U_{P-P}—peak-peak value of output

Seen from the measured waveform, the output amplitude is attenuated at 2.28V when frequency is 10 kHz; when frequency is 200 kHz, the output amplitude is attenuated at 76mV. So the output voltage attenuation is very obviously. From the equation (12), the calculated the insertion loss is 33.26 dB at 200 kHz. Compared with the simulation result, the measured result is little bad. There are three main reasons: ①there are distributed inductor and capacitor in breadboard. ②there are difference between theory simulation model and actual model of CM choke. ③ source and load impedance in actual circuit is different with that of simulation model. But, the attenuation of output voltage is still obviously.

V. CONCLUSIONS

A novel CM and DM integrated EMI filter is proposed in this paper, which is composed of one big loop type magnetic core of high permeability and two small loop type magnetic cores of low permeability. This filter has good filtering performance validated by simulation and experiment and partial experimental results is given. Because the research of integrated filter is needed to study, more work will be finished later.

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