Research of active EMI suppression strategy for high power density power supply

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***Abstract*—With the requirement of high power density converters, the volume of the EMI filter needs to shrink as much as possible. To achieve this, the feasibility of active EMI filter without magnetic components applied in high current circumstance is studied. Firstly, a novel active EMI filter without magnetic components that suppresses the CM interference is proposed in this paper. Then, the parameter design process of the filter is presented. Finally, the filter prototype and EMI hardware testbed is built. The experimental results demonstrate the efficiency and stability of the proposed active filtering method.**

Keywords—CM interference; high power density; active EMI filter; high frequency model;

I. INTRODUCTION

In the process of the design of the power supply, suppressing electromagnetic interference is an indispensable link. However, with the increase of power rate the equipment usually works in large current situation. Therefore, the volume and loss of traditional passive filter components are large under the high power and large current working status. For this reason, the power density of power supplies is difficult to increase. In other words, the volume of EMI filters has become a bottle neck of improving the power density of the whole equipment.

Hence, active EMI filters with the advantages of small size and low loss have received widespread attention. Many active filters were reported during the last decades. However, those active or hybrid EMI filters use the magnetic components inevitably, so the volume and loss of the filters will be large when the current of the main circuit increases. Therefore, the challenge to design a high performance EMI filter for high current converters still exists. This issue has acquired extensive concern of many scholars and researchers in recent years.

On considering the above mentioned problems, the motivation of this paper is trying to provide an active EMI suppression strategy for high power density power supply. To achieve this, a novel active EMI filter without magnetic components topology is proposed in the first time. Then, factors that influence insertion loss of the filter are analyzed. The design principles are indicated in detail. Finally, the experimental platform of the active EMI filter is built. The stability and filtering performance are verified through hardware test.

II. PROPOSED ACTIVE EMI FILTER

The filter proposed in this paper is mainly applied in high current circumstance. The current in this experimental platform can get to 60A. The volume and loss of inductors is very large. In order to reduce the volume of the filter and to improve the power density, the filter topology this paper adopts is voltage detection and current injection topology without magnetic components. In order to enhance the output current and power of the filter and improve insert loss (IL), a push-pull power amplifier circuit is used behind the output of the amplifier so that output current is large enough. Therefore, as for the high output current switching power supply in this paper, a high performance filter that can export large current need be designed as shown in Fig.1. The IL is large and the filtering performance is excellent.

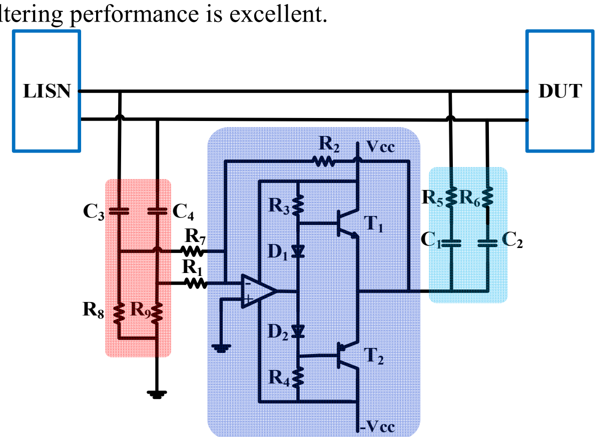


Figure 1. Proposed active EMI filter

A. Simplified model

In order to analyze the effect of the internal resistance of the interference source on IL of the active EMI filter, this paper builds the simplified equivalent model of the filter as shown in Fig.2. It can be seen from the calculation as shown in formula (1)-(3) that when the internal resistance increases, the IL of the active EMI filter will improve.

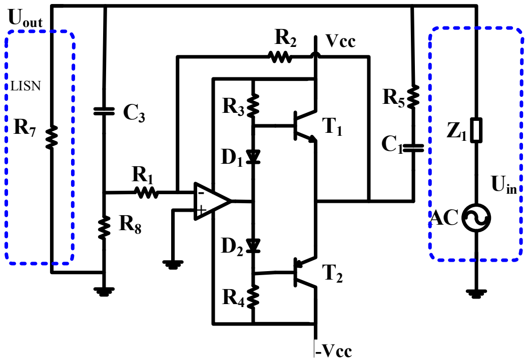


Figure 2. Simplified equivalent model

$$U_{out}=\frac{U_{in}}{1+\frac{Z_1}{Z_L}+\frac{Z_1}{Z_{C3}+R_1//R_8}+\frac{Z_1\cdot(1+\frac{R_2}{R_1})}{Z_{C1}+R_5}} \tag{1}$$

$$IL=20\lg\frac{U_{out1}}{U_{out2}}=20\lg\left[\left|1+\frac{Z_1//Z_L}{Z_{C3}+R_1//R_8}+\frac{Z_1//Z_L\cdot(1+\frac{R_2}{R_1})}{Z_{C1}+R_5}\right|\right] \tag{2}$$

When, $Z_{C3}+R_1//R_8>>Z_1//Z_L$

$$\Rightarrow IL=20\lg\left[\left|1+\frac{Z_1//Z_L\cdot(1+\frac{R_2}{R_1})}{Z_{C1}+R_5}\right|\right] \tag{3}$$

B. High frequency model and design principle

In order to ensure the high IL and stability of the active EMI filter, this paper predicts its high-frequency model. Calculate the insertion loss of the proposed circuit as the internal resistance of the interference source is 50Ω in formula (4)-(5).

$$IL=20\lg\left(\left|1+\frac{25(1+A\angle\theta)}{R_5+Z_{C1}}\right|\right) \tag{4}$$

$$=20\lg\left(\left|1+\frac{25\sqrt{(1+A\cos\theta)^2+A^2\sin^2\theta}\angle\theta'}{\sqrt{R_5{}^2+|Z_{C1}|^2}\angle\alpha}\right|\right) \tag{5}$$

The high frequency performance of amplifier will fall within the scope of the conducted interference frequency. It mainly reflects in the phase shift and the attenuation of gain. This paper analyzes the IL of the filter in high frequency through calculation and the effect of the performance of amplifier as shown in Fig.3 and Fig.4.

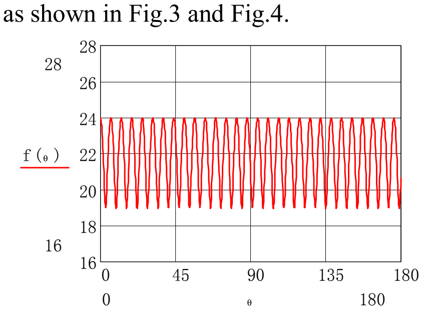


Figure 3. The effect of phase shift θ

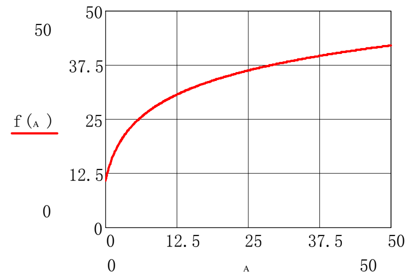
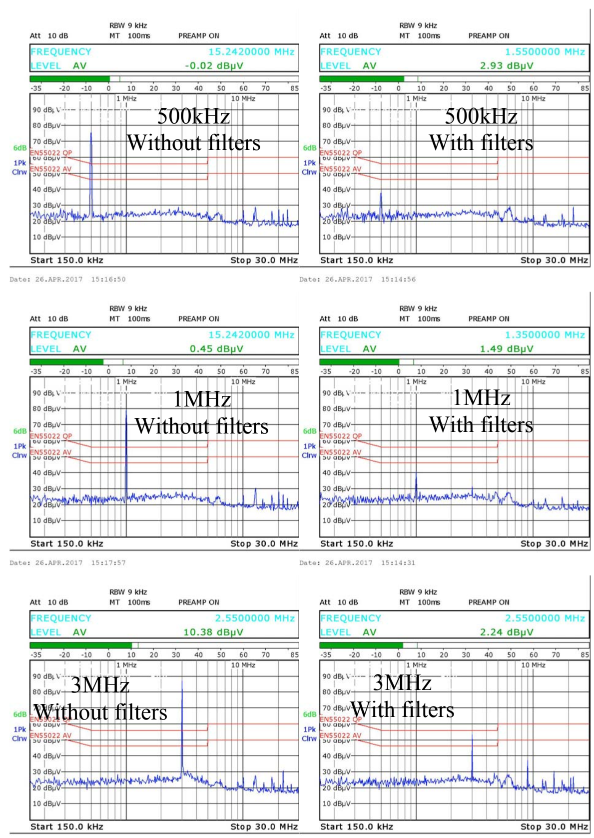


Figure 4. The effect of the gain A

It is shown that the change of insertion loss with phase shift is little from 150 kHz to 30 MHz frequency range by calculation. However, the change of IL is large when the gain of amplifier falls with the frequency rising. So the high gain of the amplifier should be ensured as far as possible when filter parameters are designed.

C. Standard interference source test results

This paper uses a standard interference source to verify performance of the active EMI filter and simulates the CM interference source with the signal generator. The internal resistance of the signal generator is 50Ω. The principle diagram is shown as Fig.2. AC is the signal generator and R7 is the equivalent impedance of LISN. This paper designs the parameters of the filter and verify insertion loss of the filter in the single frequency point through the experiment in Fig.5.



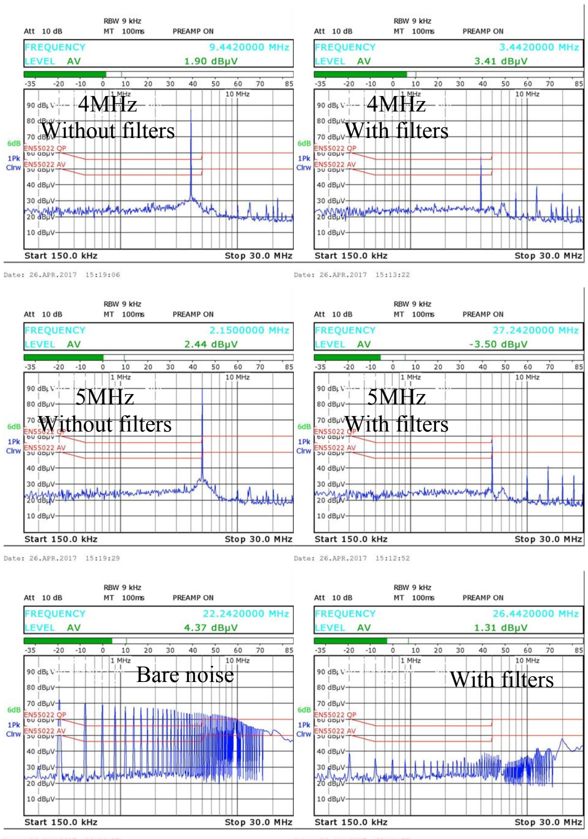


Figure 5. The filtering performance in the single frequency point

III. EXPERIMENTAL RESULTS

In order to verify the filtering performance of the active EMI filter under high current environment, this paper chooses a 3000W power supply as the CM interference source. The rated current gets to 60A. The experimental platform is as shown in Fig.6.

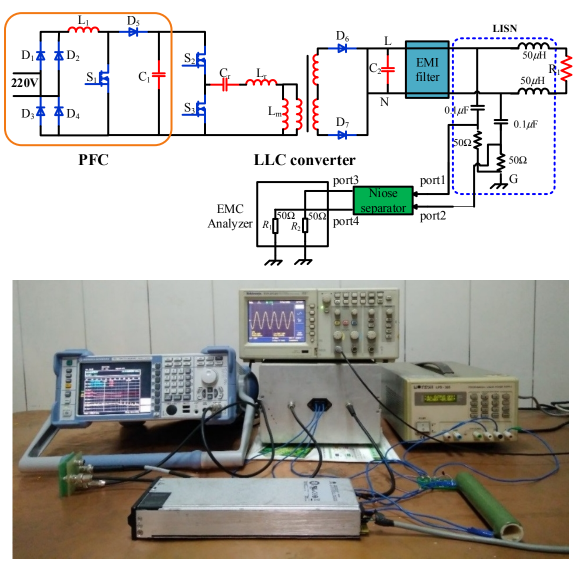


Figure 6: Schematic diagram and experimental platform picture

A 10μH inductor is adopted to increase the impedance so that the IL of active EMI filter can be enhanced. The flow chart is shown in Fig.7. The open loop transfer function is shown in formula (6). The theoretical IL is shown in Fig.8.

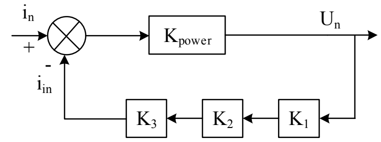


Figure 7. The flow chart

$$K_1 = \frac{R_1}{R_1 + \frac{1}{sC_3}} \quad K_2 = A * \frac{1}{1 + \frac{s}{2\pi f_a}} \quad K_3 = \frac{1}{R_{10} + \frac{1}{sC_1} + Z_s // Z_{LISN}}$$

$$K_{power} = R_{LISN} + \frac{1}{sC_{LISN}}$$

$$G = K_1 * K_2 * K_3 * K_{power} \tag{6}$$

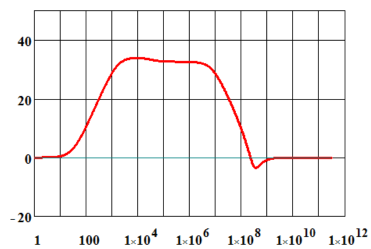


Figure 8. The theoretical IL

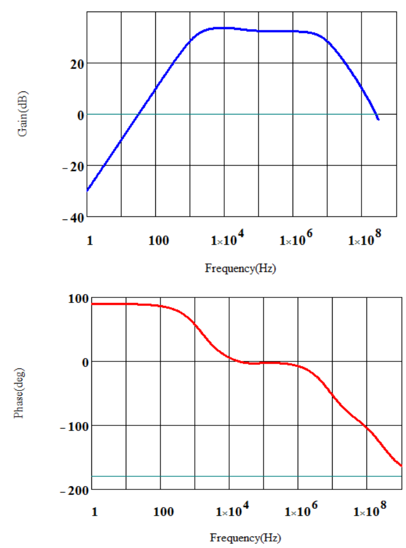
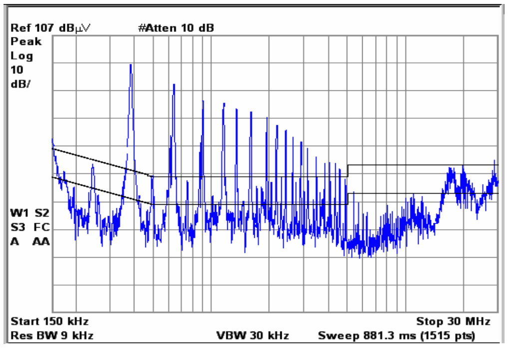
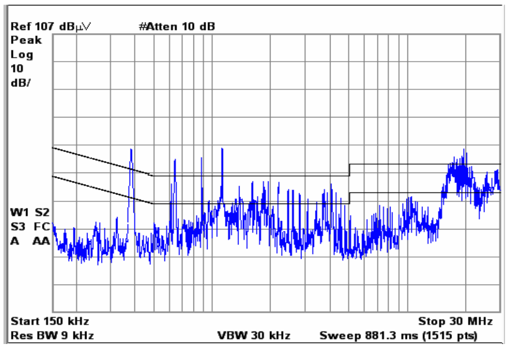


Figure 9. Bode diagram

The Bode diagram is shown in Fig.9. The stability of the filter can be ensured. The conducted interference detected on LISN is separated by differential mode and common mode separator. The CM interference separated can be observed by the EMI receiver as shown in Fig.10. (a) is the bare noise. (b) is the CM interference with the filter. It can be seen that the filtering performance is verified and the IL can get to 30dB.



(a) The bare noise



(b) The CM interference with the filter

Figure 10. CM interference for output of power supply

IV. CONCLUSION

This paper proposed a novel active EMI filter without magnetic components applied in high current circumstance. Its volume is small and the loss is low. Besides, a kind of high frequency equivalent model is predicted so that the parameters of the filter can be calculated accurately. Finally, the filtering performance of the filter applied in the standard noise source and high current power supply is verified by experiment. The proposed active EMI filter can replace traditional passive EMI filter because the IL is large enough and the stability can be ensured.

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