Jian-Hua LI*, Ting-Ting RAO, Wei-Hua WANG, Wei-Bo ZHU

Research of the EMI Suppression Circuit in the ASM Power

Abstract: As to the EMI in ASM, a power system is the main interference source and receiver. The EMI rejecting ability of power system determines the electromagnetic compatibility of ASM, so, it plays a very important role in the progress of ASM design. In this paper, we first summarize the program of switching power EMI suppression; focus on analyzing the form of switching power EMI filter. Then the ADS software was used to simulate the circuit performance of the EMI filter we designed. Through iterative simulation and optimization, an EMI filter with excellent performance which applied to ASM secondary power source is finally achieved.

Keywords: ASM; the secondary power source; EMI filter.

1 Introduction

A stable and reliable power system is the prerequisite for the safe operation of an electronic system. The purpose of secondary power sources to convert the 28V DC power that supplied by the aircraft, to various lower voltages which could be used by the missile. Besides the radiated EMI produced by other applications in the ambient environment, the power system inside the missile could also be interfered by the high frequency switching noise and rectifier diode noise in the secondary power source, which will result in output containing some severe harmonic waves both highly in amplitude and frequency. The switching noise and higher harmonic wave have severe negative effects on the EMC performance and power source stabilization, it will cause a potential threat to the system is existed without proper measurements. So an effective EMI suppression circuit must be designed in a power supply lines to keep the system work in a stable state.

2 Secondary power system EMI suppression tactics

Currently, the secondary power source in ASM, mostly use the ±28V provided by the aircraft as the input voltage, whose output voltages lie on the actual demands of the system, as ±15V, ±5V. Figure 1 shows a EMI filter diagram, used with the

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secondary power source in ASM, which consists of six blocks: voltage or current spike suppression, surge suppression circuits, input filter circuit, short-break energy storage circuit, and output filter [1]. Transient voltage suppression (TVS) diodes are usually used in the spike suppression circuit to weakening the highly transient voltage between the power lines, clamping the input voltage in a preset-value, so that others electronic elements could work normally under a safety voltage [2-4]. The function of surge suppression circuit is to deal with the overvoltage and under voltage problems when the aircraft system is in a short-break condition or high current switching [5-7]. The short-break energy storage circuit which generally made up by the current limiting resistor, high-capacity tantalum capacitors and diodes, is aimed at providing power continuously when power system is in high current switching.

The input filter is working as a frequency filter, dealing with the power signal which had processed by the spike suppression circuit and the surge suppression circuit to meet the requirements of DC-DC module, while the output filter is adjusting the DC-DC output quality to satisfy the application circuit's requirements [8].

3 Secondary power ripple suppressing method

Spike suppressing and surge suppressing can be treated as the preliminary process for the aircraft power source, providing a relatively stable environment for the secondary power source input. Standardized design has been implemented on the circuit system of ASM, causing the same kind of EMI problems, so universal EMI filters could be used in the input power lines. Considering some restrict factors, such as weight, size, function, and cost, the choice of a DC-DC converter is complicated, thus special output ripple attenuation circuit should be designed accordingly.

3.1 The sources of secondary power output noise

Figure 1 shows the secondary side circuit of the DC-DC converter. Figure 2 illustrates the output EMI noise, consisted of two parts, one is the ripple caused by the switching frequency. It's a triangular wave, whose cycle is determined by the switching frequency; the other noise is the fast transient spike voltage caused by the PCB distributed parameter at the time the DC-DC converter's working state change into ON/OFF, this spike voltage is superimposed on the peak of the triangular wave. The switching frequency is relatively low, while the frequency of transient voltage spikes is relatively high, thus the spectrum of EMI is very wide. Therefore a wide-band output filter network is supposed to increase to the DC-DC terminal to filter out high frequency noise and ripple noise.

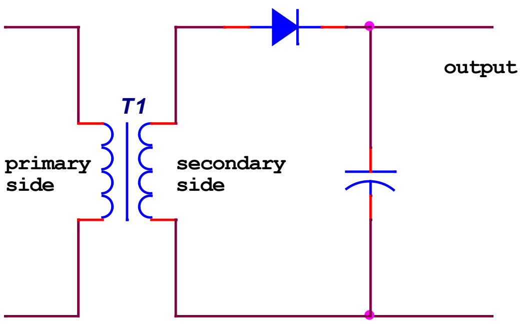

Figure 1. Diagram of the secondary circuit of switching power

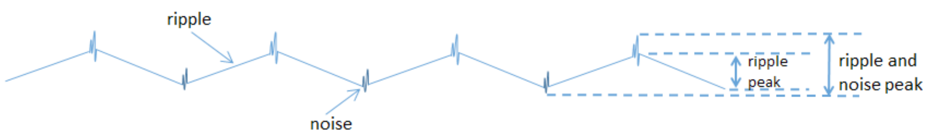

Figure 2. DC-DC switching power output noise

3.2 Filter structure

The interference signal on Secondary side power lines can be represented as differential-mode noise and common-mode noise. Differential-mode noise is the interference signal between power line L and N, common-mode noise interference is the interference signal between power line L and the ground. Thus, the suppressing to ripple noise of DC-DC converter output filter can be understood as the suppressing to common-mode and differential-mode noise. The output filter can be divided into common filter and differential filter according to the function structure.

3.2.1 General performance EMI filter

The general performance EMI filter circuit contains a common-mode choke (common-mode inductance) L, differential-mode and common-mode capacitor Cx, Cy. Common-mode choke is made up of two coils which were wounded on a magnetic ring (closed magnetic circuit)'s upper and lower half-rings with same number of turns but wounded opposite. The magnetic flux direction of the two coils is the same, and when the common-mode interference appears, the total inductance increases rapidly to a large value which can suppress common-mode interference effectively. EMI filter circuit in Figure 3 can be seen as the combination of the common-mode equivalent circuit and differential-mode equivalent circuit shown in Figure 4a and 4b and L_{dm} is the leakage inductance of common-mode choke.

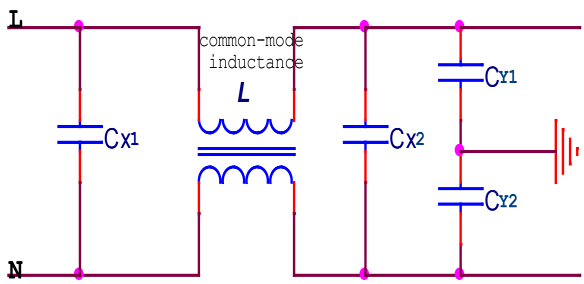

Figure 3. General performance EMI filter

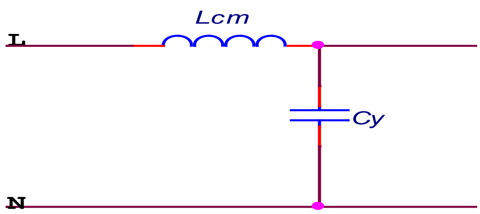

Figure 4 .(a) Common-mode equivalent circuit

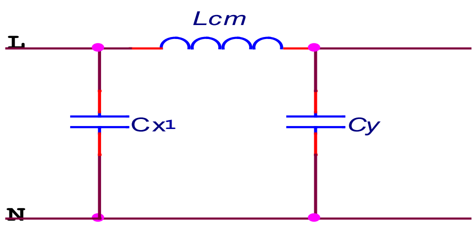

Figure 4. (b) Differential-mode equivalent circuit

Common-mode equivalent circuit A parameter matrix:

$$A = \begin{bmatrix} 1 - \omega^2 L_{cm} C_y & j\omega L_{cm} \\ j\omega C_y & 1 \end{bmatrix} \tag{1}$$

Differential-mode equivalent circuit A parameter matrix:

$$A = \begin{bmatrix} 1-\omega^2 L_{cm} C_y & j\omega L_{cm} \\ j\omega(C_{x1} + C_x - \omega^2 C_{x1} C_x L_{dm}) & 1-\omega^2 L_{dm} C_{x1} \end{bmatrix} \tag{2}$$

Take A parameter matrix value into insertion loss calculation and get the formula of common-mode equivalent circuit insertion loss:

$$\mathrm{I.L} = 10\,lg\left[\left(Z_L - \omega^2 L_{cm} C_y Z_L + Z_S\right)^2 + \left(\omega C_y Z_s Z_L\right)^2\right] \tag{3}$$

$$-20lg(Z_S + Z_L)$$

The formula of differential -mode equivalent circuit insertion loss:

$$\begin{aligned} \mathrm{I.L} &= 10\,lg[(Z_L - Z_L\omega^2 L_{dm} C_x + Z_S - Z_S\omega^2 L_{dm} C_{x1})^2 \\ &+ (\omega L_{dm} + \omega Z_S Z_L C_{x1} + \omega Z_S Z_L C_x - \omega^3 Z_S Z_L C_{x1} C_x L_{dm})^2] \\ &- 20lg(Z_S + Z_L) \end{aligned} \tag{4}$$

The formula above gives the relationship between insertion loss and circuit parameters. In practice, the filters typically work in impedance mismatch situation because the switching power resistance value changes with frequency. a special equipment could be used to measure the equivalent impedance of interference source and load, the spectrum whether the filter is used or not. After all these steps, a simulation design can be start based on EMI filter common-mode and differential-mode model.

3.2.2 Differential-mode suppressing performance enhanced filter

To strengthen the differential-mode suppression effect, one or more differential-mode inductance may be added into the general structure circuit. Enhanced differential-mode suppressing filter circuit is shown in Figure 5.

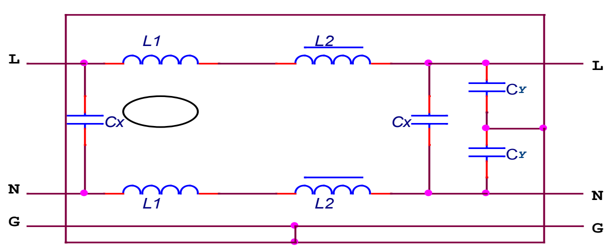

Figure 5. Differential-mode suppressing performance enhanced filter

Cx, Cy are differential-mode and common-mode capacitor, L1 is common-mode choke, L2 is differential-mode inductance, the equivalent circuit of the differential-mode suppressing performance enhanced filter is shown in Figure 6a and 6b.

In an EMI filter, common-mode circuit and differential-common circuit have a certain contribution to mutual noise. As a differential-mode inductance, L2 also exists in the L-type circuit composed of common-mode inductance L1 and capacitance Cy, and it is contributed to suppressing common-mode noise; Similarly, the leakage inductance Le of common-mode choke L, and common-mode capacity Cy, also existing in the π-type circuit target for differential-mode suppressing, will suppress differential-mode noise as differential-mode filter circuit do. Therefore, doing parameter values selecting should take the mutual contribution effect between common-mode and differential-mode circuit into account during the filter design.

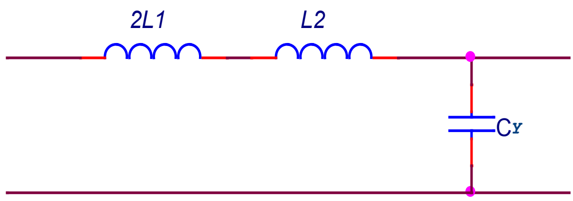

Figure 6. (a) Common-mode equivalent circuit

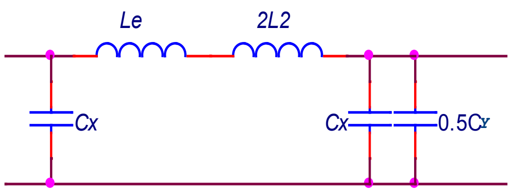

Figure 6. (b) Differential-mode equivalent circuit

4 EMI filter design and simulation analysis of ASM secondary power

4.1 Filter schemetic design suppressing DC-DC output ripples, including one level common-mode filter and three level cascade differential-mode filters.

To suppress common-mode noise more effectively, the common-mode choke with high permeability, good high-frequency performance core should be given priority. Common-mode choke inductance values are related with current ratings. Differential capacitor Cx usually select metal film capacitors, in the range of 0.1 ~ 1μF. Cy is used for suppressing high frequency common-mode interference signals, often select ceramic capacitor with high self-resonance frequency. Since connect to ground, Cy will produce the common-mode leakage current Iid, and the leakage current will cause harm to human security, so the leakage current should be as small as possible, typically <1.0mA. Common-mode capacitance varies with the size of the leakage current, it should not be too large, generally in the range of 2000~4700pF.

4.2 Simulation optimization

The simulation of Circuit system is divided into pre-simulation and post-simulation. Pre-simulation does not need to consider the PCB layout information and directly do a simulation of the circuit schematic by connecting the discrete devices. While post-simulation take the distribution parameters of PCB layout and routing into consideration. Take Figure 8 as the input excitation signal and post-simulating the Figure 7 EMI filter network, each node's waveforms of the filter shows in Figure 9.

In Figure 9, the waveform with glitch is the output voltage of the first stage differential-mode inductance. The waveform marked by blue line is the output voltage of the second stage differential-mode inductance. The waveform marked by symbol is the output voltage of filter terminal. Compared with the input signal of 300mV ripple fluctuations, output ripple amplitude of every differential inductance is very small, less than 15mV, and the signal spikes are completely filtered out in final output port. In ADS pre-simulation, it looks like the trend of waveform in each node is reasonable, but the suppression is too ideal. The reason is that the signal path is not taken into consideration, while the layout situation and the discrete devices parameters should be combined when doing a simulation.

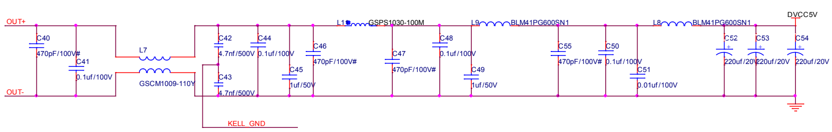

Figure 7. Power EMI filter circuit

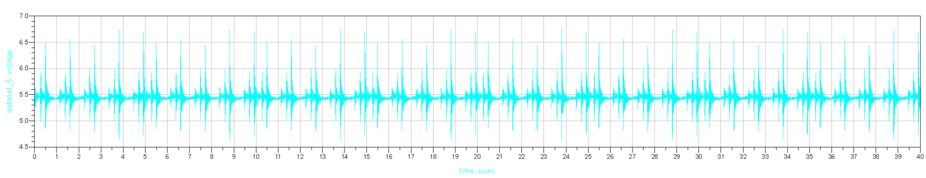

Figure 8. Input power signal with different frequency

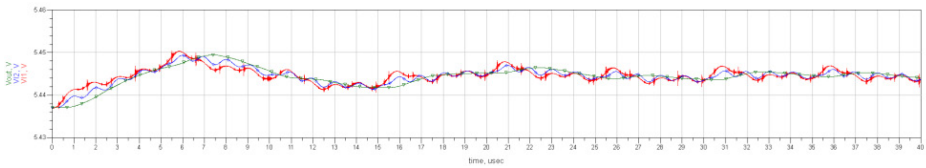

Figure 9. Output voltage at input frequency(the unit “usec” means “microsecond”)

Figure 10 shows the connecting information after importing Allegro PCB layout with discrete devices, Figure 11 shows a simulation result for the system layout optimization.

Draw a comparison between Figure 11a and 11b, we can get that the EMI filter circuit can suppress most of the interference signal. Meanwhile, the spike can be suppressed, but not completely be eliminated.

Figure 12 is the actual test waveform of Figure 11, from the comparison of Figure 11 and 12; it is highly similar both in ripple value (80mV and 100mV respectively) and fluctuation of waveform.

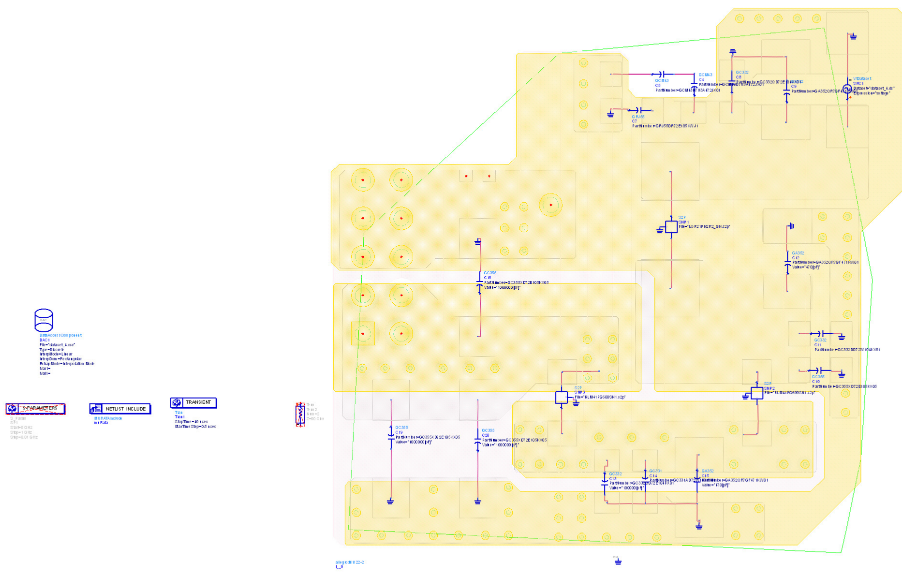

Figure 10. EMI co-simulation circuit

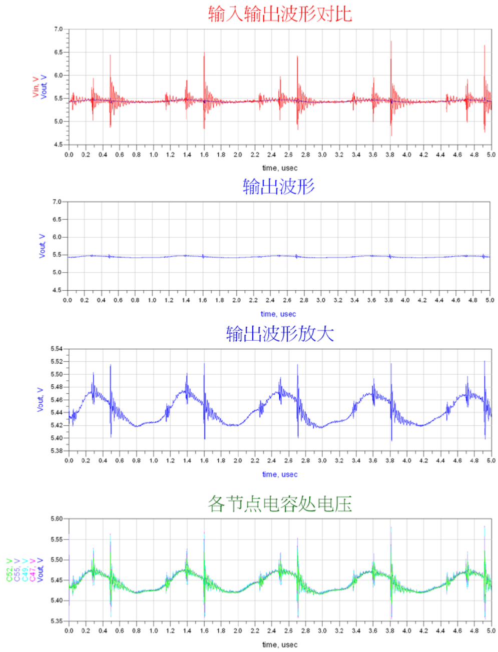

Figure 11. (a) The input and output voltage comparation of co-simulation

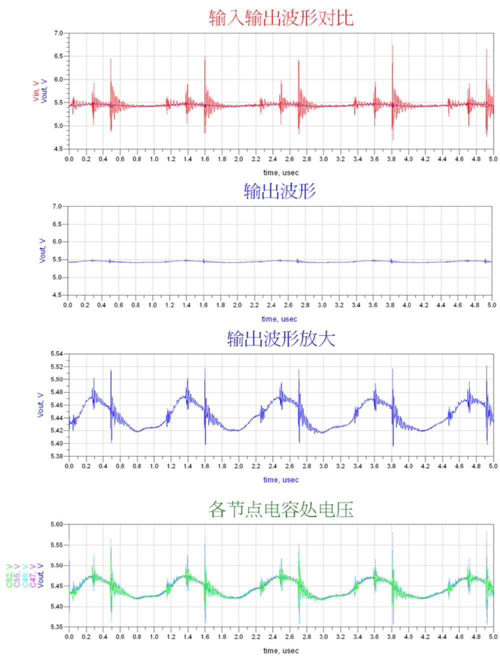

Figure 11. (b) The output voltage of co-simulation

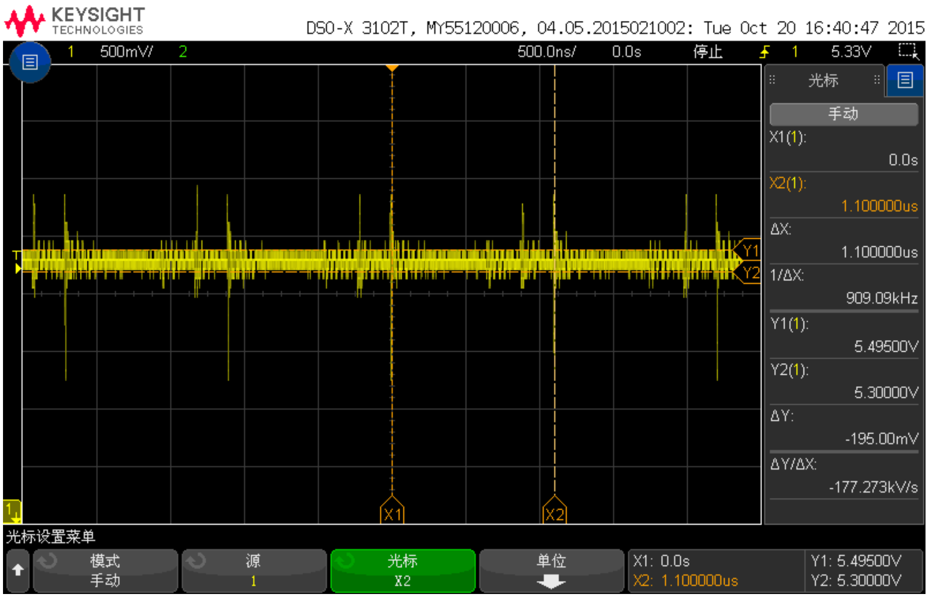

Figure 12. Waveform of measured output

5 Conclusion

In this paper, an EMI filter circuit is designed specified for the switching power which ranges widely in switching frequency and has high-frequency harmonics. By simulating and optimizing the circuit, the output waveform of the simulation results is familiar with the actual test results, which not only prove the reasonability of filter structure selection, the setting of device parameters, and the circuit layout, but also show that making use of the post-simulation can better predict the performance of the power design and provide optimization support for the EMI filter circuit of ASM secondary power.

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