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Suppression Approaches of Far-Field Radiated Emission Using Common-Mode Inductor

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Abstract

The miniaturization and integration of Switching Mode Power Supply (SMPS) is increasing, making it more complicated to analyze and predict its far-field radiated emission, and, consequently, studying the suppression method of far-field radiated emission of SMPS is of practical significance and engineering value. In this paper, a high-frequency SMPS is selected as the research object, whose far-field radiated emission is measured under the condition of three typical suppression methods. The experimental results verified the effectiveness of common-mode inductor and are of reference value for EMC design of power converter.

Keywords: SMPS; EMC; Far-field Radiated Emission;

Introduction

With the increase of switching power supply power density and switching frequency [1-3], the far-field electromagnetic interference generated by it has become increasingly serious, which not only affects the normal operation of nearby electronic equipment, but also causes the far-field electromagnetic radiation to exceed the standard. The electromagnetic compatibility certification of the electrical and electronic systems it powers fails to pass the corresponding standards, which leads to the inability to put the product on the market. Therefore, the problem of far-field electromagnetic interference has become a problem and challenge in the design of switching power supplies

Three conditions are required to generate electromagnetic interference: first, the source of the interference; second, the coupling path; and third, the sensitive equipment. The source of electromagnetic interference of switching power supply mainly comes from the high voltage change rate (dv/dt) and high current change rate (di/dt) generated by the power switching device during the on and off process. They are related to the parasitic inductance and the parasitic capacitance acts and interacts with the parasitic inductance and parasitic capacitance in the PCB wiring, and induces drastic changes in noise. These noises are emitted through wires or space-coupled radiation to form electromagnetic interference. To eliminate electromagnetic interference, at least one of the three elements needs to be removed. One of them is to change the coupling path.

For this reason, this paper adopts different suppression measures for the coupling path of the far-field radiation of the switching power supply and conducts experimental verification. It has certain reference value for further studying the mechanism of the far-field radiation of the switching power supply and the corresponding suppression measures.

Radiation Model of Electric Dipole

Far field radiation field strength analysis is the most basic and important issue in the study of electromagnetic interference. The far-field radiation intensity is affected by various factors, such as the type of far-field radiation source, the space medium, and whether there are reflecting and refracting objects around the radiation source. Due to the complexity of electromagnetic interference analysis, electric dipoles and magnetic dipoles are the simplest form of radiation emission in electromagnetic field theory. The long cable type switching power supply can be regarded as a radiating antenna with an electric dipole as a basic unit. The basic principle of the electric dipole is analyzed below.

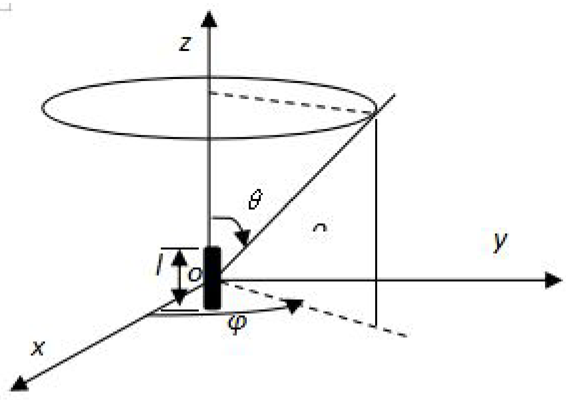

Figure 1: CM inductor connected tothe near-end ofconverter module

An electric dipole is a sufficiently short current-carrying wire that is much shorter than the wavelength and does not take into account the delay effect. It is also a basic part of a wire antenna. Any antenna can be superimposed by a series of basic elements, a section of its linear current element. The vibration amplitude of this current element is evenly distributed, its length is l (l << λ), and its phase is the same. It is assumed that the current distribution on the electric dipole is uniform, and it alternates in the wire, forming a closed loop in the space medium. The electric dipole is located at the origin O of the spherical coordinate and is placed along the z-axis. The electromagnetic field generated in the surrounding space is shown in Figure 1.

According to Maxwell Equations, the electric field intensity Ê and magnetic field intensity Ĥ of the far-field radiation can be obtained. When r>> λ / 2π, the far-field electric field strength and magnetic field strength of the electric dipole are:

$$\hat{E}_\theta \approx j\frac{I\Delta l\beta_0^2}{4\pi\varepsilon_0 r}\sin\theta\, e^{-j\beta_0 r} \quad (1)$$

$$\hat{H}_\theta \approx j\frac{I\Delta l\beta_0^2}{4\pi\omega r}\sin\theta\, e^{-j\beta_0 r} \quad (2)$$

Î is the current phasor, β_0 is the phase constant, ε_0 is the dielectric constant in vacuum, and r is the radial distance from a point in space to the origin. Among them, the electric dipole analysis shows that the electric field intensity and magnetic field intensity of the far-field radiation generated by a cable of any length can be analyzed and calculated through the current distribution of a long cable.

For cables that are electrically long, we can divide the cable into short elements, in which the phase shift of current can be neglected. Therefore, the electrically long conductors can be analyzed as several amounts of electrical dipoles.

In the Boost converter (Figure 2), the wires connected to the input-side power supply are twisted-pair cables; C_1 and C_2 are parasitic capacitances between the cable and the infinite ground plane; node N_0 is the drain and inductance of S on the P_{CB} In the area where L and diode D are connected, the parasitic capacitance between it and the infinite ground plane is C_{CM}. When the converter operates, the voltage and current at the node N_0 are abruptly changed, so that the transistor S becomes a noise voltage source V_n. In the high-frequency range (30 to 1000 MHz), the capacitors C_{in} and C_{out} can be regarded as short circuits, and the inductance L can be regarded as open circuits. The common-mode current flow path is shown by the dashed line in Figure 2.

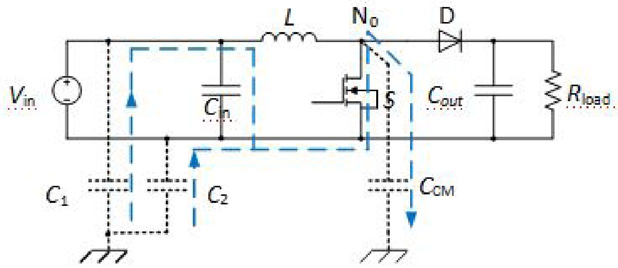

Figure 2: The Topology of Boost converter

Suppression Method of Far-Field Radiation

In the 3m anechoic chamber, a high-frequency switching power supply module is used as the test object (Figure 3). The main technical indicators of the module are shown in Table I.

This test found that when the power module is working normally, some low-frequency bands exceed the enterprise standard (solid red line in Figure 4), so adding a common-mode inductor to the output cable and taking shielding measures to verify the effectiveness of the far-field radiation suppression method

Table 1: Parameters of the (2+1) transmission line

Parameters	Values
Input AC and DC voltage /V	220
Output DC voltage /V	48
Output DC current /A	30
Rated power /kW	1.8
Weight /kg	9

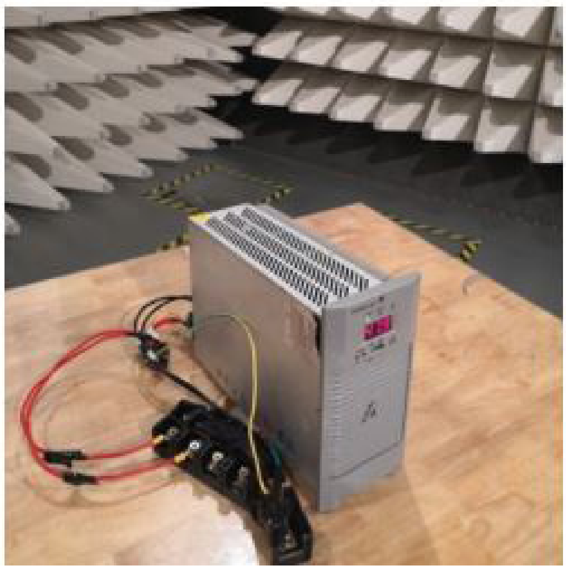

Figure 3: CM inductor connected tothe near-end ofconverter module

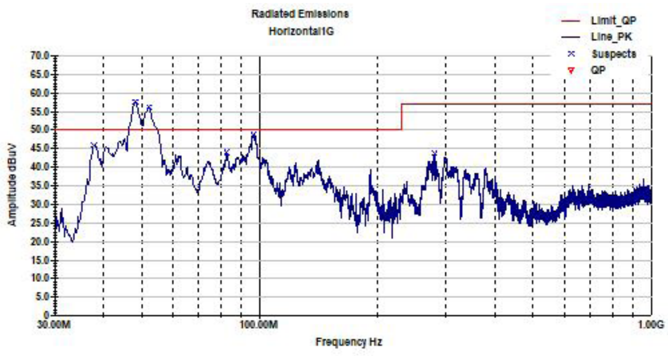

Figure 4: Far field radiation field during normal operation.

Effect of chassis on far-field radiation

Metal shielding case is one of the most used electromagnetic shielding technology in switching power supply. The metal casing can not only play a supporting and fixing role, but also can reduce the incident energy of external electromagnetic waves and reduce the emission of the electromagnetic interference of the switching power supply itself, thereby suppressing the interference. Therefore, a metal case is added to the high-frequency switching power supply module to measure the far-field radiation intensity.

The experimental results show (Figure 5) that below 35MHz, (60~100) MHz has a suppression effect of about 10dB. The remaining low-frequency bands have increased radiation after adding a casing. For bands above 100MHz, generally speaking The shell has little effect on the far-field radiation intensity.

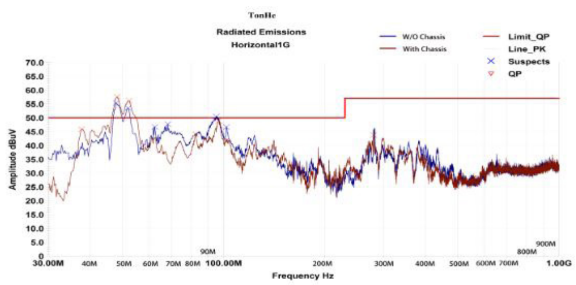

Figure 5: Effect of chassis on far-field radiation.

Effect of cable shielding on far-field radiation

For a switching power supply with a long input and output cable, the long input and output cable constitutes an electric dipole antenna and is the main contributor to the far-field radiation interference. Therefore, the output cable of the power module is shielded (not grounded) with a copper network to measure the far-field radiation intensity.

The experimental results show (Figure 6) that when the shielding layer is not grounded, it has a suppression effect of about 5dB on the frequency bands of (150~200) MHz and (200~300) MHz, and the other frequency bands have no suppression effect on far-field radiation, and even The phenomenon that the radiation intensity increases in the frequency band below 90MHz appears. The reason is that the effect of the shielding layer is not mainly due to the reflection and absorption of the electric field and magnetic field by the metal body itself but is caused by the grounding of the shielding layer. In addition, due to the large number of holes in the metal copper mesh, when the size of the holes is at half a wavelength, it also becomes an effective “slot antenna”, which has an enhanced effect on far-field radiation, resulting in a phenomenon of enhanced radiation

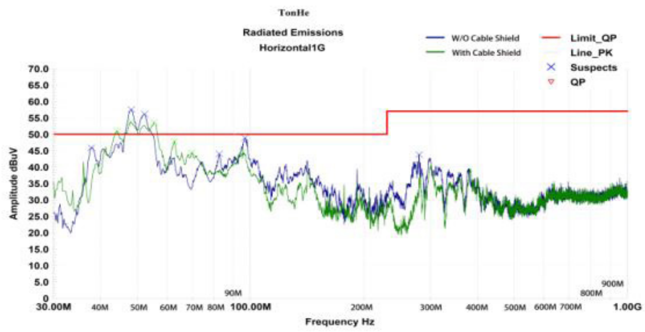

Figure 6: Effect of cable shielding on far-field radiation

The effect of the series common-mode inductance of the cable on the far-field radiation (with the case and the common-mode inductance close to the converter)

When the normal signal current flows through the common-mode inductor, the currents generate opposite magnetic fields in the coils wound in the same phase to cancel each other out. At this time, the normal signal current is mainly affected by the coil resistance (and a small amount of damping due to leakage inductance). When a common-mode current flows through the coil, due to the isotropy of the common-mode current, a magnetic field in the same direction will be generated in the coil to increase the inductive reactance of the coil, making the coil appear high impedance and generate strong damping Effect, the common mode current is attenuated, thereby reducing the far-field radiation caused by the common mode current. Connect 1mH, 2mH, and 3mH common mode inductors respectively in series to the output cable near the power module end to measure the far-field radiation intensity. All inductors share the same dimensions of ferrite core, which is 63*38*25 mm (for outer and inner radius and thickness); the only differences between the CM inductors are the turns of coils.

The experimental results show (Figure 7) that the common-mode inductor in series near the converter has a significant suppression effect on radiation. Below 300MHz, except for the case where the radiation is enhanced in the range of (68 ~ 120) MHz, there are obvious suppression effects, and the high frequency band effect is not obvious; when the 2mH common mode inductor is connected in series, the radiation intensity of each frequency is higher than that when it is connected in series 1mH There is a relatively obvious reduction; the situation of a series 3mH common mode inductor is ideal, there is no frequency band with a significant increase in radiation intensity, and the suppression effect is significantly below 62MHz and (130~300) MHz.

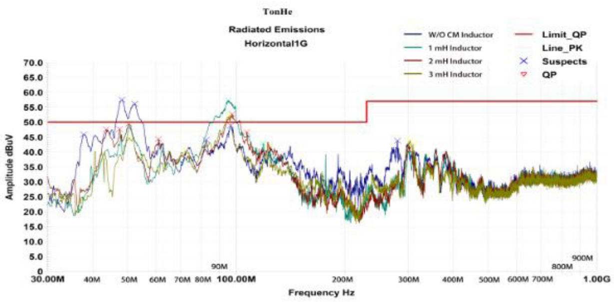

Figure 7: Effect of series common mode inductor on radiation (common mode inductor close to converter)

The effect of the series common-mode inductance of the cable on the far-field radiation (with the case and the common-mode inductance close to the load)

The 1mH, 2mH, and 3mH common mode inductors are serially connected to the output cable near the load end, and the far-field radiation intensity is measured.

The experimental results (Figure 8) show that at (35~55) MHz, there is a (5~10) dB suppression effect; as the frequency increases, the suppression effect decreases significantly, and even the radiation enhancement effect appears. Compared with the conclusions in 1.3, the radiated current in the cable is an important contributor that mainly generates far-field radiation. The closer the common mode inductance is to the power module, the less the common mode current component of the radiated current in the output cable. The better field radiation suppression effect.

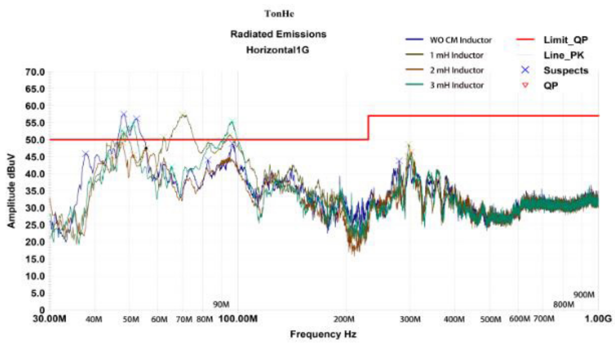

Figure 8: Effect of series common mode inductor on radiation (common mode inductor close to the load)

Conclusion

In summary, the radiation current in output cable is the main contributor to the far field radiation. When CM inductor is connected to the near-end of converter module, radiated emission is inhibited considerably, and, in contrast, CM inductor in the far-end has little effect. In addition, it is discovered that chassis of power module and shielding layer of cable hardly do anything to choke far-field radiation.

(1) Adding a metal case to the high-frequency switching power supply module, the suppression effect is obvious below 35MHz and in the range of (60~100) MHz, and the other low-frequency bands have a stronger radiation emission after adding the case, both in the high-frequency band above 100MHz small differences.

(2) When the shielding layer is not grounded, it has a suppression effect of about 5dB on the frequency band of (150 ~ 200) MHz and (200~300) MHz. The suppression effect of other frequency bands is not obvious, and even the phenomenon of increased radiation intensity appears. The reason is that the effect of the shielding layer is not mainly due to the reflection and absorption of the electric field and magnetic field by the metal body itself, but is caused by the grounding of the shielding layer. In addition, due to the large number of holes in the metal copper mesh, when the size of the holes is At half a wavelength, it also becomes an effective "slot antenna", which has an enhanced effect on far-field radiation, resulting in a phenomenon of enhanced radiation.

(3) The radiation suppression effect is obvious for the series common mode inductance of the output cables close to the converter. When the 1mH common mode inductor is connected in series, it has a significant suppression effect under 300MHz, except for the radiation enhancement in the range of (68 ~ 120) MHz, and the high frequency band effect is not obvious; when the 2mH common mode inductor is connected in series, the radiation at each frequency The intensity is significantly reduced when compared with 1mH in series; the situation of 3mH common-mode inductors in series is ideal, and there is no frequency band with a significant increase in radiation intensity, and the suppression effect is significantly below 62MHz and (130~300) MHz.

(4) Change the position of the common mode inductor in series, and connect the output cables near the load end in series with 1mH, 2mH, and 3mH common mode inductors, respectively. At (35~55) MHz, there is a (5~10) dB suppression effect; as the frequency increases, the suppression effect decreases significantly, and even the effect of radiation enhancement appears. It can be seen that the radiated current in the cable is an important contributor that mainly generates far-field radiation. The closer the common-mode inductance is to the power module, the less the common-mode current component in the radiated current, and the better the far-field radiation suppression effect

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