EMI Analysis of a Switching Power Supply

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Abstract. Switching power supply is easy to produce electromagnetic interference in the working process. Switching power supply is both an interference source and a sensitive device. Therefore, the boost circuit of switching power supply is modelled and simulated. It is concluded that the surge current and peak voltage generated by the boost circuit are the main causes of electromagnetic interference. According to the reasons, the electromagnetic interference suppression measures are proposed. It mainly includes three measures, namely adding capacitors at both ends of the switching tube, adding a filter circuit at the low voltage input end of the switching power supply, adding an optical coupler equipment and adding a common-differential-mode synthetic choke coil filter. These measures all effectively reduce the influence of electromagnetic interference of the switching power supply, and they are beneficial to improve the reliability of the switching power supply.

1. Introduction
A switching power supply is a power supply that uses metal-oxide-semiconductor field-effect transistor (MOSFET) to control the voltage at the output terminal. Because the switching power supply has the characteristics of small size, few components, low cost and high electrical efficiency, it is widely used in life.

Electromagnetic compatibility (EMC) means that when power electronic equipment is placed in an electromagnetic environment, the environment will neither affect the normal operation of the equipment nor interfere with other equipment in the electromagnetic environment. It includes electromagnetic interference (EMI) and electromagnetic susceptibility (EMS) [1]. EMC problem includes three basic elements: interference source, interference transmission path and sensitive equipment [2]. EMI consists of conducted emission interference and radiated emission interference. The root cause of EMI is the surge current and peak voltage caused by $dv/dt$ and $di/dt$ during system operation [3]. Switching power supply is both an interference source and a sensitive device. The source of interference is mainly boost circuit. As a boosting device, the boost circuit will generate electromagnetic radiation noise during the boosting process. The noise will be transmitted to other modules by the transmission line, which will affect the operation of the module. According to the electromagnetic interference problem of switching power supply, this paper studies the reason of electromagnetic noise by modelling and simulation of switching power supply circuit, and proposes a method to suppress electromagnetic noise.

2. The principle of switching power supply circuit
The switching power supply is mainly composed of boost circuit, PWM control and feedback circuit, and low-voltage power supply. Figure 1 shows the composition diagram of switching power supply.
The boost circuit produces mainly electromagnetic interference in the switching power supply. The switching power supply adopts low-voltage and low-power DC drive scheme to avoid excessive current required for energy transmission. The principle of the boost circuit: it is composed of a switch tube, an inductor L, a capacitor C, a rectifier diode and a PWM square wave generation module, as shown in Figure 2. The PWM module generates a square wave signal with adjustable duty cycle. Boost circuit has two working modes: discontinuous conduction mode (DCM) and continuous conduction mode (CCM) [4]. When the boost circuit is in DCM mode, the output voltage increases. The PWM control module generates a square wave signal with an adjustable duty cycle to control the on-off of the switch. When the switch tube is in the on state, the inductor is charged. When the switch tube is in the off state, the rectifier diode is turned on, and the inductive energy transfers to the capacitance and resistance [5].

When the switch is in the on and off state transitions, the inductor L current changes from the minimum value \( I_{limin} \) to the maximum value \( I_{limax} \). When the switch is closed, the power supply charges the inductor L, and the inductor voltage transformation relationship is shown in (1):

\[
V_L = V_i = L \frac{d\alpha_n}{dt} = L \frac{dI_{on}}{dT} \quad (1)
\]

\( V_L \) is the inductor voltage when the switch is closed, \( I_{on} \) is the loop current when the switch is closed, \( D \) is the on-time duty cycle of the switch, \( T \) is the switching period, \( dI_L = \frac{V_i D T}{L} \).

When the switch is in the off state, the inductor energy is released, and there is:

\[
V_o V_i = L \frac{dI_{off}}{dt} = L \frac{d\alpha_{off}}{(1-D)T} \quad (2)
\]

\[
dI_{off} = \frac{(V_o-V_i)(1-D)T}{L} \quad (3)
\]

\( V_o \) is the output voltage, \( V_i \) is the input voltage, and \( I_{off} \) is the inductor current when the switch is off. According to the volt-second characteristic of the inductor:

\[
\frac{dI_{on}}{dI_{off}} = \frac{dI_f}{dI_{off}} \quad (4)
\]

\[
\frac{V_i D T}{L} = \frac{(V_o-V_i)(1-D)T}{L} \quad (5)
\]

Thus \( V_o = \frac{V_i}{1-D} \). Therefore, the on-time duty cycle \( D \) of the switch is controlled to obtain the corresponding output voltage.

### 3. Analysis of conducted interference of boost circuit

As shown in Figure 3, the boost circuit model was established in the design studio of CST to study the conducted emission (CE) of boost circuit. The input voltage was 15V, and the switching frequency was 50kHz. The active devices such as high-frequency switching tube and rectifier diode were
replaced by the SPICE model. The PWM square wave generator were replaced by port excitation. Probes were added to each part of the component to monitor the voltage and current in the circuit. The total simulation time was set as 50ms, the cycle as 0.02ms and the duty cycle as 95%.

![Boost circuit CST model](image1)

Figure 3. Boost circuit CST model

![Boost waveform](image2)

Figure 4. Boost waveform

As shown in Figure 4, it can be seen that the voltage is stable at about 300V from the simulation waveform after power-on for about 45ms.

Ideally, the waveform generated is a square wave by the PWM square wave generator. However, in the actual situation, there will be a sharp turn-off voltage due to leakage sensation [6], when the switch tube is turned off from the conduction moment. This electromagnetic interference will transmit to other modules through the circuit, the circuit causes harmonic interference.

![PWM square wave](image3)

(a) PWM square wave

![Voltage waveform](image4)

(b) Voltage waveform
Figure 5 shows the current and voltage waveforms of the switch tube obtained by CST simulation, in which the red is the PWM square wave waveform, the blue is the voltage waveform of the switch tube, the yellow is the current waveform. The $\frac{dv}{dt}$ and $\frac{di}{dt}$ cause inrush current and voltage spikes during circuit operation, which make the voltage and current waveforms different from reality. The interference generated by the boost circuit is divided into common mode interference and differential mode interference. For the electromagnetic noise generated by switching tubes, the Fourier analysis method is generally used. Fourier transform is performed on the voltage and current waveforms obtained by the simulation, so as the spectrum waveforms of the voltage and current is obtained.

The PWM square wave performs take the Fourier transform in CST to obtain the spectrum diagram of the PWM square wave, as shown in Figure 6.

As shown in Figure 7, it is comparison of PWM square wave spectrogram with spikes and normal PWM square wave spectrogram. It can be seen that the noise of the normal PWM square wave is much lower than that with spikes at high frequencies. Therefore, the problem of spike noise should not be neglect.
4. Conducted interference suppression measures
Filter circuit can be added to the low-voltage input end of the boost circuit to suppress the problem of common-mode noise. The types of filter circuits mainly include: capacitor, RC and LC filter circuit. The filter circuit is connected in parallel with the switch tube to achieve good suppression of common-mode interference. The filter circuit can smooth out the spikes.

4.1. Add optical coupler equipment
The optical coupler equipment transmits electrical signals that uses light as the medium. The optical coupler equipment is composed of a light-emitting diode and a phototransistor, and the diode and the triode are isolated from each other. The light-emitting diode is the signal input end. The phototransistor is the signal output end. The optical coupler equipment realizes the mutual conversion between the optical signal and the electrical signal. Due to the electrical isolation of the two parts of the circuit, the electrical noise interference can be effectively suppressed at the output end. As shown in Figure 8.

![Figure 8. Schematic diagram of optical coupler equipment](image)

Because optical coupler equipment transports signal from light-emitting diode to phototransistor, and it cannot be transmitted in the reverse direction. It has the ability of one-way transmission. The output signal has no effect on the input signal. The input signal and the output signal are completely electrically isolated, so the anti-EMI ability is strong. For circuits using switching power supply as power supply, the circuit is easily affected by the conduction interference of switching power supply and will function or fail in advance. Therefore, optical coupler equipment is used to electrically isolate these signals.

4.2. Add a common-differential-mode synthetic choke coil filter
The common-differential-mode synthetic choke coil filter are generally composed of discrete components such as common-mode inductors, differential-mode inductors and capacitors [7], as shown in Figure 9.

![Figure 9. Common-Differential-Mode Synthetic Choke Filter](image)

Because the boost circuit is the interference source, the common touch and differential mode noise generated by the high voltage converter will interfere with the propagation path of other modules, and common-differential-mode synthetic choke coil filter can effectively suppress the propagation of electromagnetic interference and cut off the transmission path of interference.

5. Conclusion
The switching power supply is the main source of interference. The boost circuit of switching power supply is modelled and simulated. It is concluded that spikes and ringing are the main causes of interference. According to the reasons, the electromagnetic interference suppression measures are
proposed. These measures include mainly: adding capacitors at both ends of the switching tube, adding a filter circuit at the low voltage input end of the switching power supply, adding an optical coupler equipment and adding a common-differential-mode synthetic choke coil filter. These measures can effectively reduce the conduction interference of the switching power supply. It is beneficial to improve the reliability of circuit operation.

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