

Analysis and research of EMI filter based on SiC power device

Zheng Liu

Guangdong University of Technology, NO. 100 Waihuan West Road, Panyu District, Guangzhou City, Guangdong Province, CHN

1061834667@qq.com

Abstract. The new electronic devices represented by SiC have brought new opportunities to improve the efficiency and power density of the drive circuit system. However, the complex circuit drive system using the new electronic devices still faces many challenges to give full play to its advantages. This paper focuses on the electromagnetic interference of drive circuit. Research on Filter Circuit, through in-depth study of the filter circuit, several second-order active circuits are proposed to filter the signal interference of the conduction path. Finally, an adjustable quality factor bandstop circuit is designed. The proposed circuit has good adjustment and feedback functions when filtering interference signals.

Keywords: SiC Driving Circuit, Electromagnetic Interference, Second Order Active Filter Circuit.

1. Introduction

In recent years, a new wide energy gap semiconductor device represented by SiC, with its excellent material properties, has broken through the performance limit of traditional Si-based devices, and has gradually become a research hotspot in the industry [1].

SiC is a compound semiconductor material composed of silicon and carbon. Its energy gap is large (3.2 eV, about 3 times that of silicon-based materials), High breakdown field strength (about 10 times higher than silicon-based materials), Large electron saturation migration rate (twice as large as silicon-based materials), High thermal conductivity (3 times higher than silicon-based materials), It has many advantages such as high frequency and high efficiency, high voltage resistance, high temperature resistance, strong radiation resistance and stable chemical properties[2]. Therefore, SiC devices are often used in circuit design to meet the requirements of high frequency and high voltage. SiC MOSFET is also being used in grid-connected inverters and electronic power transformer, the power device SiC MOSFET can effectively reduce the power loss of the device, and it is expected that SiC devices will be more widely used in the future power system [3-5].

However, since the SiC drive circuit can work at a higher switching frequency and has a faster switching speed, its electromagnetic interference (EMI) generated in actual operation is more serious than that of the ordinary Si drive circuit. Excessive electromagnetic interference not only makes the equipment unable to pass the corresponding electromagnetic interference standards, but also may have an impact on the control circuit, and may even lead to misoperation of protective equipment. Therefore, in the design of SiC drive circuit, how to reduce the electromagnetic interference in the circuit becomes

a problem that cannot be ignored. Power engineers usually use buffering, filtering, resonance and other technologies to solve the electromagnetic compatibility of power products [6,7].

A circuit that is selective to the frequency of a signal is called a filter circuit that enables a signal within a specific frequency range to pass, and prevents a signal outside that frequency range from passing. According to the different passband frequencies, it can be divided into four filtering circuits: low-pass filter (LPF), high-pass filter (HPF), band-pass filter (BPF) and band-stop filter (BEF) [8,9]. In this paper, the EMI generation mechanism of SiC drive circuit is analyzed, and several filtering circuits are proposed to solve the EMI problem in SiC drive circuit.

This paper is divided into three parts: introducing SiC power devices, exploring the principle of electromagnetic interference, and introducing the filter circuit. In the principle part of the filter circuit, the typical structure of the second-order active filter is proposed, and the second-order active low-pass filter circuit and band-stop filter circuit are also introduced.

2. Principle of emi

The occurrence of electromagnetic interference must have three basic conditions: the first is the electromagnetic interference source, such as cosmic rays, the external interference generated when the blower works. The second is the path to spread electromagnetic interference energy. The third is the response of the disturbed object. Therefore, electromagnetic interference source, interference propagation coupling path and sensitive devices are called three elements of electromagnetic interference.

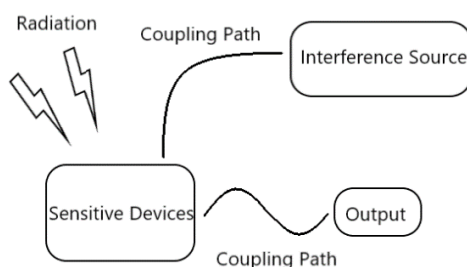


Figure 1. Three elements of electromagnetic interference.

According to the different properties of the transmission medium, the transmission of electromagnetic energy from the interference source to the sensitive device has two forms of conduction coupling and radiation coupling. When the electromagnetic interference energy is transmitted along the visible connection circuit between the interference source and the sensitive equipment and the capacitance and mutual inductance between the conductors, the conduction coupling interference is generated. When transmitting outward in the form of electromagnetic waves through space, the radiation coupling interference is generated [10].

Single event Burnout (SEB) refers to the damage mode caused by the impact of neutrons and heavy ions that occasionally enter the ground caused by cosmic rays, which is considered to be the main reason for the accidental failure of high-voltage power components. In particular, compared with the location at 0 m above sea level, the neutron concentration will be as high as more than 10 times, which is prone to problems. Usually, the voltage derating of components and devices with low failure rate is adopted to reduce the risk of accidental failure caused by cosmic rays.

Electromagnetic interference in conducted coupling is usually filtered by filters, such as common-mode inductance in circuit system. Common-mode inductance is also called common-mode choke ring, which is commonly used to filter common-mode electromagnetic interference signals in switching power supply.

3. Circuit Analysis

3.1. Typical structure of second-order active filter

Filter circuits are generally divided into active filter circuits and passive filter circuits, The active filter circuit can make the amplitude frequency characteristic steep. Although the design of passive filter is simple and easy, the amplitude frequency characteristic is not as good as active filter. The actual production is often used to the second-order active filter circuit, the typical structure of the second-order active filter is shown in Fig. 2

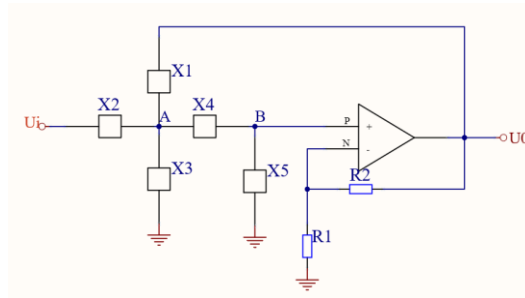


Figure 2. Typical circuit of second-order active filter.

$X_1 \sim X_5$ are transadmittances, consider $U_p = U_n$, according to KCL, the general expression of transfer function can be obtained [11]

$$G(s) = \frac{U_0(s)}{U_i(s)} = \frac{A_{uf} X_1 X_4}{X_5(X_1 + X_2 + X_3 + X_4) + [X_1 + X_2(1 - A_{uf}) + X_3] X_4} \quad (1)$$

in (1), $A_{uf} = 1 + R_f/R_1$.

3.2. Design of second order active low pass filter

Low-pass filter is suitable for waveform generation circuit, pulse amplification circuit, etc. When designing low-pass filter, its cutoff frequency, quality factors and other parameters are generally considered. The cutoff frequency formula $f_0 = f_n = \frac{1}{2\pi RC}$, Select the capacitance C1 and C2 values, calculate the resistance values, the second order active low pass filter circuit is shown in Fig. 3.

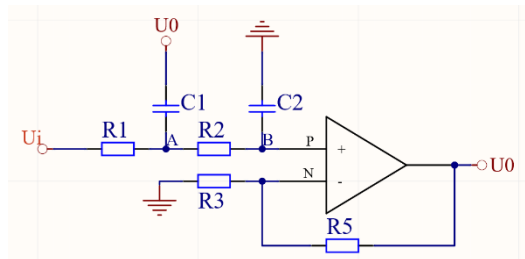


Figure 3. The second order active low pass filter circuit.

From (1), The transfer function of the voltage-controlled voltage source second-order active low-pass filter is

$$G(s) = \frac{U_0(s)}{U_i(s)} = \frac{G_0 \omega_n^2}{s^2 + \xi \omega_n s + \omega_n^2} \quad (2)$$

in (2), ω_n is characteristic angular frequency, ξ is damping coefficient.

The operational amplifier and resistor constitute the voltage-controlled voltage source. The operational amplifier is the in-phase input, which has the advantages of high input resistance and low output resistance. It can provide certain model gain and buffer effect, and is easy to tune. This circuit is widely used in numerical control devices and signal processing circuits. Second-order active low-pass

filter filters high frequency noise in the signal, but when the input signal frequency is large, the amplification effect of the circuit is not ideal.

3.3. Active bandstop filter circuit

Bandstop filter is suitable for filtering a narrow band frequency in a wide frequency range. It is often used to suppress parasitic passband generated by band pass filter to protect useful signals. If the band-stop filter circuit is paralleled by high-pass filter and low-pass filter, the cut-off frequency of low-pass filter must be lower than that of high-pass filter. The basic second order active bandstop filter circuit is shown in Fig. 4.

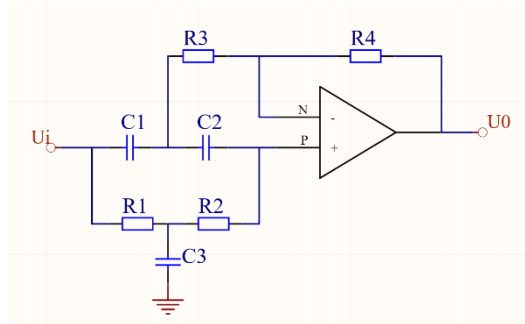


Figure 4. Active bandstop filter circuit.

R_1 , R_2 , C_3 and C_1 , C_2 , R_3 constitute a dual-T frequency selection network [11]. Using the same phase input, high input resistance, low output resistance, operational amplifier provides amplification and buffering. In the circuit, R_1 and R_2 is the same as R , C_1 and C_2 is the same as C , the resistance of R_3 is $R / 2$, the capacitance of C_3 between R_1 and R_2 is $2C$. Central Frequency of Bandstop Filter $f_0 = \frac{1}{2\pi RC}$, when $f=f_0$, the gain is zero, showing the band-stop characteristic [12,13].

3.4. Driver IC

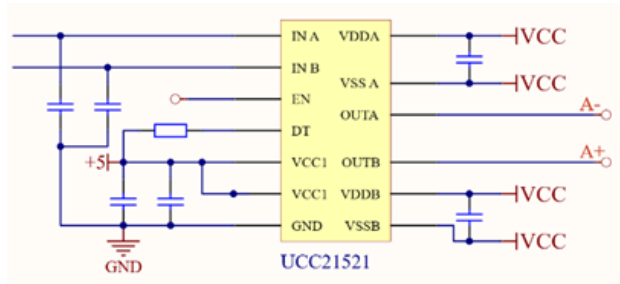


Figure 5. SiC MOSFET driver IC.

The driver chip is UCC21521 chip from TI Company in the United States, it can meet the requirements of SiC driver. The isolation voltage between input and output reaches up to 1500 V, and the common mode disturbance rejection voltage reaches more than 100 V / ns. The typical value of signal transmission delay is 19 ns, and the current of 4 A can be provided at work.

3.5. SiC Driving Circuit and Bandstop Filter Circuit

The whole circuit is divided into SiC drive circuit and band-stop filter circuit. The active band stop filter circuit adopts a dual-t frequency selection network with adjustable quality factors, which controls the signal in a certain frequency band to receive great attenuation, which makes it almost impossible to pass, while the signals in other frequency ranges can pass smoothly. The bandstop filter circuit is mainly used to eliminate the useless signals of some known frequencies in the drive circuit, so as to reduce the interference to the required signals. A filter circuit is designed to Filter EMI interference, so as to

completely filter the signal of a certain frequency band and its second harmonic interference in the output voltage U_0 .

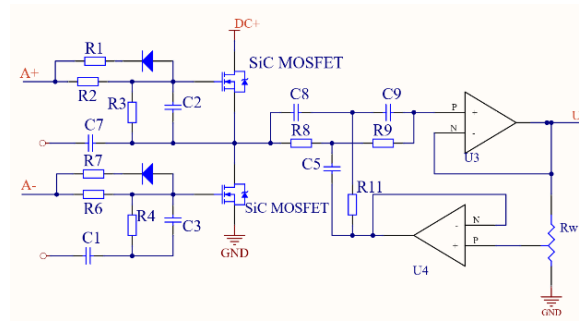


Figure 6. SiC driving circuit and bandstop filter circuit.

The central frequency of bandstop filter is $f_0 = \frac{1}{2\pi RC}$, for 200Hz power frequency, design stopband center frequency. In circuit design, let $C_8=C_9=0.02\mu\text{F}$, then $R_8=R_9 \approx 39.8\text{k}\Omega$, $C_5=0.04\mu\text{F}$, then $R_{11} \approx 19.9\text{k}\Omega$, if for the 20Hz power frequency, let $C_8=C_9=0.04\mu\text{F}$, then $R_8=R_9 \approx 199\text{k}\Omega$, $C_5=0.08\mu\text{F}$, then $R_{11} \approx 99.5\text{k}\Omega$.

This band-stop filter circuit adds the operational amplifier and potentiometer R_w with feedback function on the basis of the traditional filter circuit, the function of R_w is to adjust the quality factor Q of the circuit. The larger the Q value is, the narrower the stopband width is, and the better the frequency selection characteristics are [14].

4. Conclusion

SiC power electronic devices will play more and more advantages in improving power efficiency and meeting high frequency and high voltage [15,16]. SiC devices will be more widely used in the future. In this paper, the electromagnetic interference of SiC drive circuit is discussed. The second-order active low-pass filter and the second-order active bandstop filter are introduced. The working principle of the filter circuit is studied, and the transfer function is analyzed. Based on the basic second-order active filter circuit, a bandstop filter circuit is proposed in the paper to adjust the frequency selection characteristics according to the resistance value of the potentiometer. The resistance value and capacitance of the bandstop filter circuit are calculated by the bandstop center frequency. The circuit has good filtering, feedback and amplification functions, and has good effect in dealing with the signal interference problems of intermediate frequency signal and low frequency signal.

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