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Design of the GaN HEMT in Half-Bridge Power Converter

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Abstract

The introduction of new Wide Band Gap (WBG) power semiconductor devices enables the power converter to break through the limitation of efficiency and power density, so as achieving the goal of high efficiency, light-weight and small size. This article proposes a 200VDC/48VDC 500W output half-bridge power converter, and it uses Gallium Nitride (GaN) High Electron Mobility Transistor (HEMT) to test the efficiency. The frequency of switching can be high up to 250kHz. Mutual verification of the miller effect and the value of probe loading error caused by high frequency.

Keywords: Gallium Nitride(GaN); Half-bridge converter; Miller effect; Probe loading; High Electron Mobility Transistor(HEMT)

Abbreviations: GaN: Gallium Nitride; HEMT: High Electron Mobility Transistor; EMI: Electro Magnetic Interference; SMP: Switching Power Supply

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Introduction

In the era of energy shortage, effective use of energy has always been the main research goal. Switching Power Supply (SMPS) conversion technology has been widely used in daily products. In recent years, switching power supplies are moving towards high efficiency, light weight and small size [1]. In recent years, system designers and product manufacturers have adopted a light-weight, thin, short, and small size as their product features. However, due to materials, Si-MOSFETs have their physical limitations at switching frequencies. As a result, because of the limitation of switching frequency and conduction loss, the product design of other components, cores and heat sinks are also limited. After the advent of Gallium Nitride (GaN), changes in materials and advances in manufacturing technology, the switching frequency of Gallium Nitride FETs surpassed the limits of Si-MOSFETs, even high up to 1MHz [2]. Compared with Si-MOSFETs, Gallium Nitride FETs have lower $R_{DS(ON)}$ and switching losses. However, with the frequency increases, the Miller effect and the RC effect are intensified. The Miller effect generates V_{GS} through C_{GD} and C_{GS} which may affect the operation of the actual circuit. Due to the input capacitance and input resistance measurement of different instruments, the RC effect will cause different waveform results. This kind of converter is applied to higher input voltage. The power switches T_1 and T_2 and capacitors C_1 and C_2 can be selected with lower withstand voltage (Figure 1). In addition, the function of capacitors C_1 and C_2 is voltage division [3], and the two capacitors must be connected in series and have a large capacitance value, that can make capacitor voltage be $V_i/2$. The voltage divider resistors R_1 and R_2 mainly balance the voltage divider capacitance values C_1 and C_2 to avoid voltage unevenness caused by electrolytic capacitor error value, that cause the ripple voltage on the secondary side to be larger. The C_3 capacitor is mainly used to avoid uneven voltage division, resulting in unbalanced magnetic flux of the transformer and saturation (DC blocking).

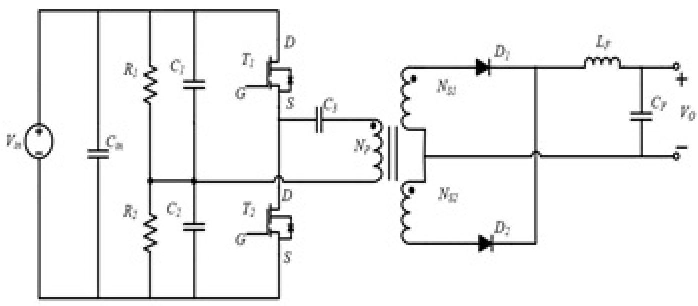

Figure 1: System architecture diagram.

Experimental Results

Design a half-bridge circuit in continuous current mode to verify its waveform and efficiency under the circuit's specifications. Since the dead time is the smallest at 100% load rate, the energy of the leakage inductance has the least impact on the components in the circuit. Thus, the GaN switching voltage is V_{DS2}, the voltage on the primary side of the transformer. The oscillations of V_{NP}, current i_{NP}, and output rectifier diode i_D are all minimal. The output voltage V_0=47.8V, the output current I_0=10A, and the output power is 480W. See (Figure 2), the efficiency of applying GaN to a half-bridge converter at a switching frequency of 250kHz is about 90%. Compared with the traditional half-bridge circuit, the full-load efficiency is 5% higher. And under the same withstand voltage conditions, the $R_{DS\ (on)}$ of a GaN switch is 5-8 times smaller than the Si switch, and the withstand current is higher. These differences give GaN switches the advantages of high efficiency and high power density. When the driving signal V_{GS} is a low voltage signal, the drain-source is turned off and the V_{DS} voltage rises rapidly. It has a higher dv/dt under high-frequency switching, thereby enhancing the Miller effect [4]. As a result, the Miller voltage generated on V_{GS} causes drain-source misconduct and the circuit is destroyed (Figure 3). The $V_{GS(th)}$ of most GaN is only 1.1-1.3V. In the design, attention should be paid to the selection of the driver, the size of the driving resistance R_G, the parasitic capacitance of GaN, and the circuit layout to reduce the loop. There are two paths for the Miller effect: red flows to the driver and green flows through C_{GD} and C_{GS}. The current flows to the red reduce the voltage generated by the blue loop and the influence of the Miller effect. The design goal is to make the Miller voltage lower than $V_{GS(th)}$, so that the GaN switch does not conduct.

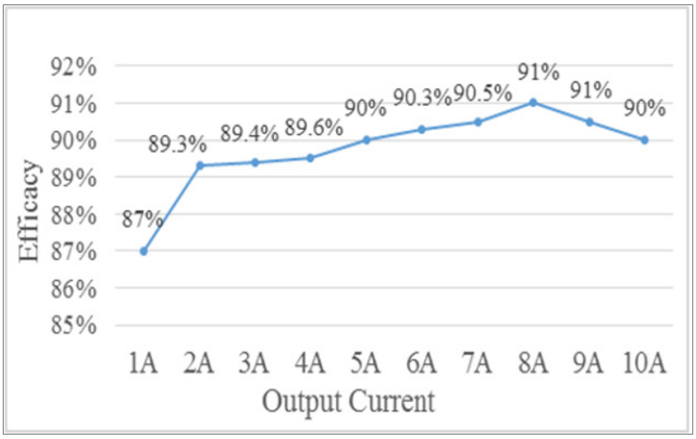

Figure 2: Design of half-bridge converter with GaN HEMT at 250kHz.

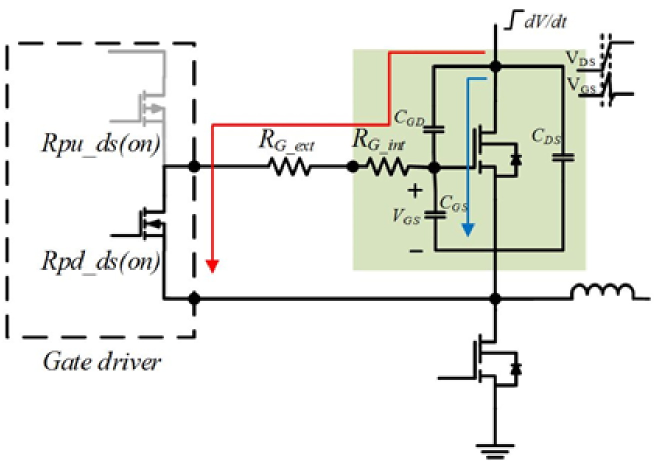

Figure 3: Miller effect path.

Conclusion

The GaN power components have successfully applied to isolated half-bridge converters. The switching frequency of 250kHz is 3-5 times higher than the general switching frequency. That is, the required values of capacitors, inductors, and transformer cores are less than 3-5 times. That is greatly reduce the size of peripheral components and core. As the switch conduction loss decreases, the goal of high power density, high efficiency, and small size have achieved. Although the power density and efficiency of the converter are improved, the disadvantages are relatively amplified. The higher the dv/dt during high-frequency switching, the more serious the Miller effect and electromagnetic interference (EMI) problems. These will be the problems that high-frequency power converters in the future.

Acknowledgement

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