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Research on High Power Density Control Board of Permanent Magnet Synchronous Motor

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Summary

In high power density inverter, the size of the control board also plays an important role. Designing a small, full-featured, high-performance and reliable main control board is extremely important in high-power density permanent magnet synchronous motor inverter.Using TI's 32 bit floating point single core TMS320F28335 digital signal controller as the control core, power supply circuit, clock circuit, reset circuit, analog sampling circuit, position and speed detection circuit and communication interface circuit are described in detail. The platform hardware structure is simple and the dynamic and static properties are excellent. The high power density main control board is 85mm long and 60mm wide. The main control board has a high-power experiment on a 83kW controller. The experimental results show that the control performance of the main control board is good and reliability .

Keywords: inverter, control, power density , permanent magnet motor, reliability

1 Introduction

The high power density main control board not only needs to find the most suitable package size, but also must design a simplified and practical functional circuit. The high power density main control board has six PWM outputs, which can realize vector control of AC permanent magnet synchronous motor; six IGBT overcurrent protection signal inputs; two motor phase current signal sampling channels, one bus voltage signal sampling channel, two temperature signal sampling channels; one resolver signal decoding circuit, and its output is 12-bit SPI serial digital signal; one CAN communication; complete protection functions, including IGBT overcurrent protection, bus voltage overvoltage protection, motor phase current overcurrent protection, controller over temperature protection and motor over temperature protection.The functional block diagram of the board is shown in Fig. 1.

This paper describes in detail the design of the power supply circuit, reset circuit, analog sampling circuit, position and speed detection circuit and communication interface circuit in the control circuit, and present a high power density PCB design board which length is 85mm and width is 60mm.

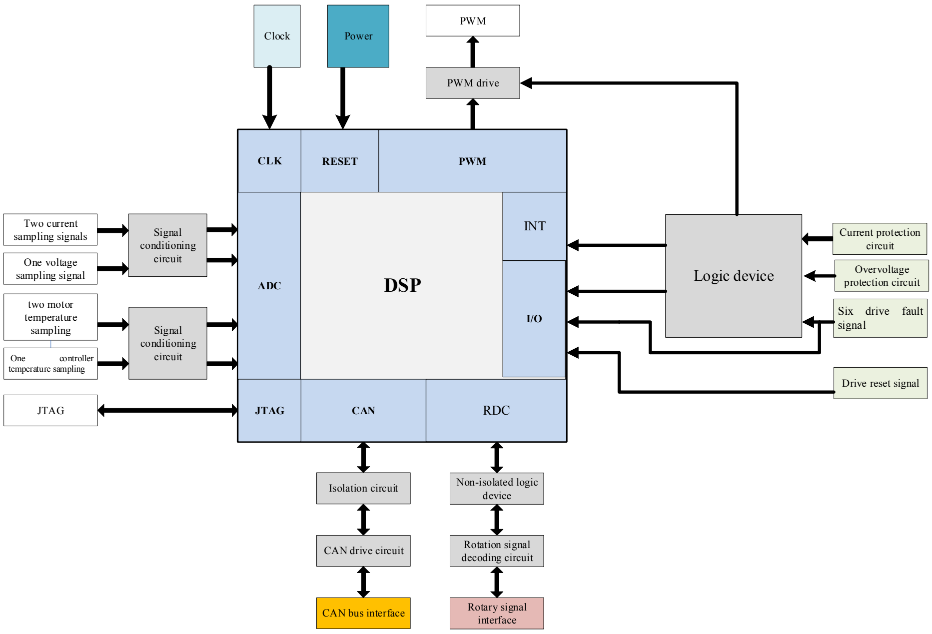

Figure1: Circuit block diagram

2 Technical principle

2.1 Power circuit

The main control board uses a lot of power, mainly +5V, +3.3V, +1.9V, +5V_RDC, +12V_RDC. All power supplies are common and are non-isolated power supplies. In addition, +3.3V and +1.9V respectively supply +3.3VA and +1.9VA to power the AD module of the DSP through LC filtering.

The 24V to 5V power module is LMZ35003. The LMZ35003 power module is an easy-to-use integrated power solution that combines a 2.5-A DC/DC converter with a shielded inductor and passives into a low profile, QFN package. This total power solution allows as few as five external components and eliminates the loop compensation and magnetics part selection process. The small 9 mm × 11 mm × 2.8 mm, QFN package is easy to solder onto a printed circuit board and allows a compact point-of-load design with greater than 90% efficiency and excellent power dissipation capability.

The IO voltage 3.3V and the core voltage 1.9V chip for the DSP are TPS767D301. The TPS767D3xx family of dual voltage regulators is designed primarily for DSP applications. These devices can be used in any mixed-output voltage application, with each regulator supporting up to 1A. Power circuit shown in Fig. 2.

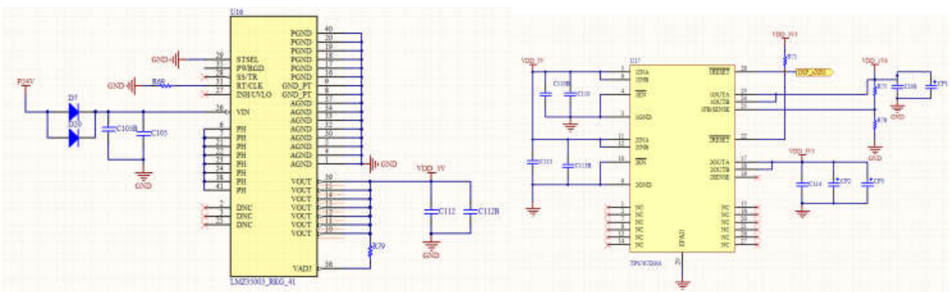

Figure2: Power circuit

2.2 AD sampling circuit

The main function of the AD sampling circuit is to convert and condition the level of the analog signal such as current, voltage, temperature, etc. to meet the voltage range requirement of the ADC analog input channel (the voltage range of the ADC analog input channel of the TMS320F28335 is 0V~+3V).

In the current sampling circuit, the current transformer converts the motor phase current into a low-voltage signal. In order to meet the requirements of the DSP analog input voltage range, the low-voltage AC voltage signal needs to be conditioned before entering the DSP. The motor phase current conditioning circuit is shown in Figure 5. The input signal is first divided by a resistor, then passed through a primary voltage follower, and finally passed through a second-order low-pass filter into the DSP analog input channel. The voltage follower has a large input impedance and a low output impedance. Its function is to improve the load capacity and anti-interference ability of the signal. Adjusting the resistance and capacitance values of the second-order filter circuit can achieve different signal cutoff frequencies. AD sampling circuit shown in Fig.3.

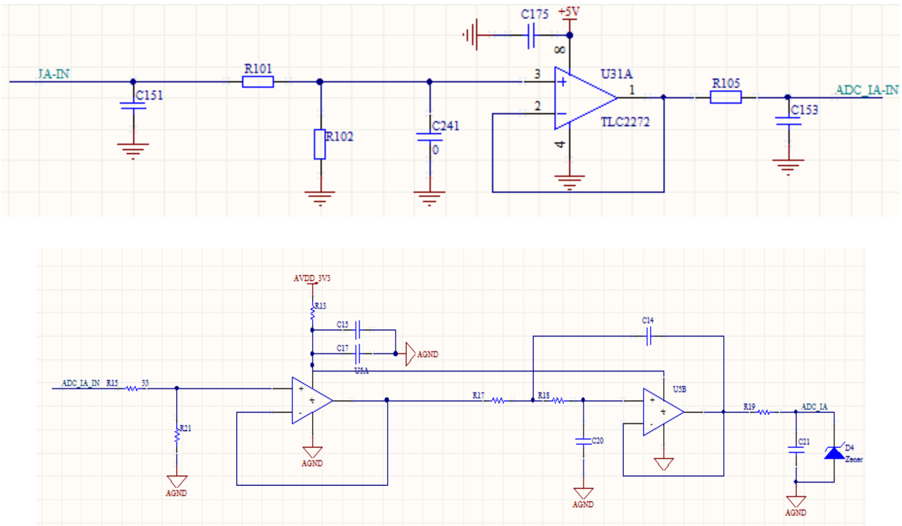

Figure3: current sampling circuit

The relationship between the output of this conditioning circuit and the input is：

$$U_{ADC\_IA} = \frac{3}{5} U_{IA\_IN}$$

Uy represents the voltage value of the AD sampling after passing through the conditioningcircuit, and Ux represents the output voltage value of the Hall current sensor.

The DC bus voltage sampling circuit uses a differential circuit, andthe maximum input sampling voltage can reach 1100V. Thecircuit is simple, low cost, fast response, high accuracy andinsensitive to temperature. In order to ensure samplingaccuracy, using low temperature drift and high-precisionresistors and the latest high-precision differential amplifierTLC2272-Q1 which has low noise, low-input bias current andfully-specified for both single-supply and split-supplyoperation. Also, in order to enhance the electrical insulationand increase immunity, bus voltage sampling circuit of thepositive and negative of the differential input are located in thetop layer and the low layer of the PCB layout. The schematicdiagram of the voltage sampling circuit is shown in Fig.4. U1B is used as a voltage follower, which can isolate the high voltagesignal and the low voltage signal.

The relationship between the output of this conditioning circuit and the input is：

$$U_{ADC\_UDC} = (U_{DC+} - U_{DC-}) \cdot (\frac{R_{34}}{R_{27} + R_{28} + R_{29}})$$

Where U_{ADC_UDC} is output voltage value of the conditioning circuit,U_{DC+} is the positive end of the DC bus,

U_{DC-} is the negative end of the DC bus.

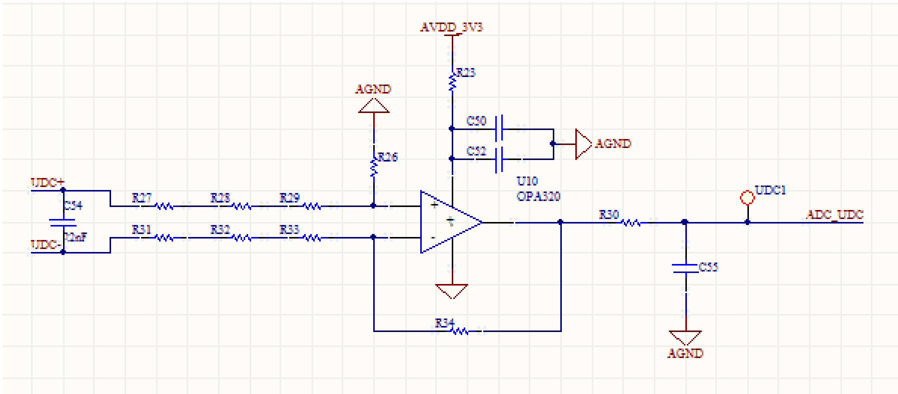

Figure4: voltage sampling circuit

2.3 Position and speed detection circuit

Rotor position is one of the most critical physical quantities in vector control. AC permanent magnet synchronous motors generally use a resolver to measure rotor position and motor speed. The main function of the resolver signal detection circuit is to decode the analog signal output from the resolver into a digital signal and communicate with the DSP through the SPI interface.

The core chip for position and speed detection is AD2S1210. The AD2S1210 is a complete 10-bit to 16-bit resolution tracking resolver-to-digital converter, integrating an on-board programmable sinusoidal oscillator that provides sine wave excitation for resolvers. The excitation signal is amplified using AD8397. The AD8397 comprises two voltage feedback operational amplifiers capable of driving heavy loads with excellent linearity. The common-emitter, rail-to-rail output stage surpasses the output voltage capability of typical emitter-follower output stages and can swing to within 0.5 V of either rail while driving a 25 Ω load. Position and speed detection circuit shown in Fig.5.

AD2S1210 has two working modes: configuration modeand normal mode. Configuration mode is used to program theregisters, to set AD21210 excitation frequency, resolution andfault detection threshold. Configuration mode also can be usedto read register fault information of the position and velocity, and storage of data. AD2S1210 can complete the work in theconfiguration mode, or after the completion of the initialconfiguration to leave work configuration model in normalmode. Under normal mode work and output data can provideangular position and angular velocity data. A0 and A1 inputsused to determine whether AD2S1210 in configuration modeand whether the position or velocity data to the output pin.Fig.6 is AD2S1210 excitation signal output waveform and AD2S1210 input sine waveform.

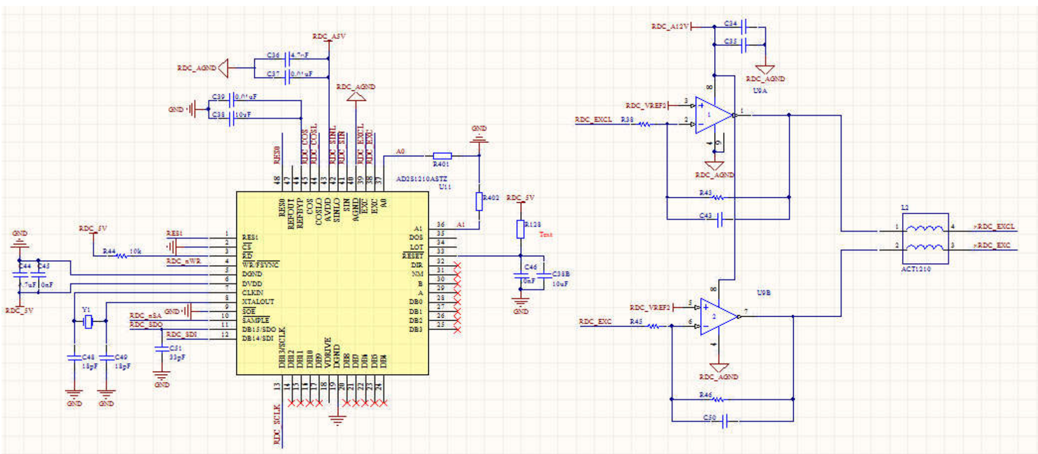

Figure5: Position and speed detection circuit

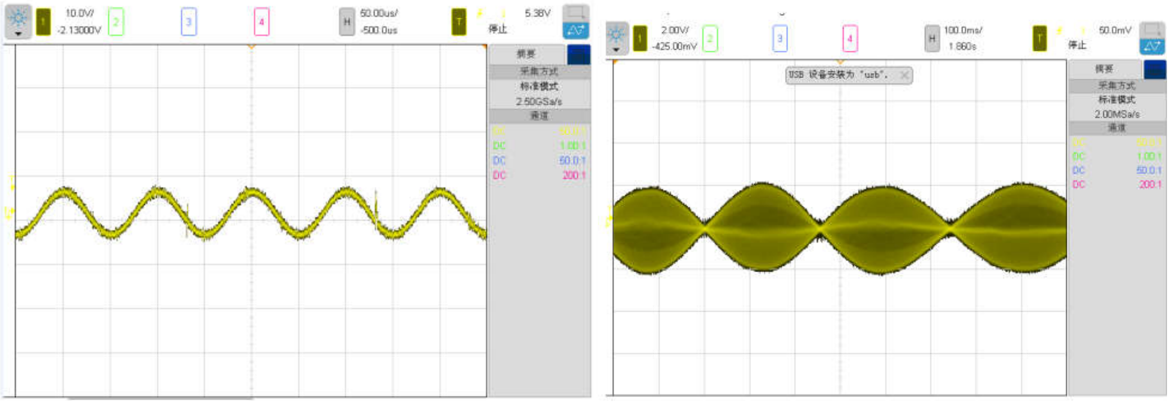

Figure6: AD2S1210 excitation signal output waveform and input sine waveform.

2.4 CAN communication circuit

There is a CAN controller module in the DSP chip that supports the CAN2.0B protocol, so only one CAN transceiver can be used in the CAN interface circuit.The main control chip of CAN communication is ADM3053. The ADM3053 creates a fully isolated interface between the CAN protocol controller and the physical layer bus. It is capable of running at data rates of up to 1 Mbps. In addition, the filter capacitors CH, CL, and CDF are used to filter out noise interference signals on the CAN bus, which can further improve the anti-jamming performance and reliability of the CAN interface. CAN interface circuit shown in Fig.7.

The CAN circuit communicates with the host computer on the PC, and the communication at the high power 81 kW experiment is always normal. The Fig.8 shows the communication host computer display interface.

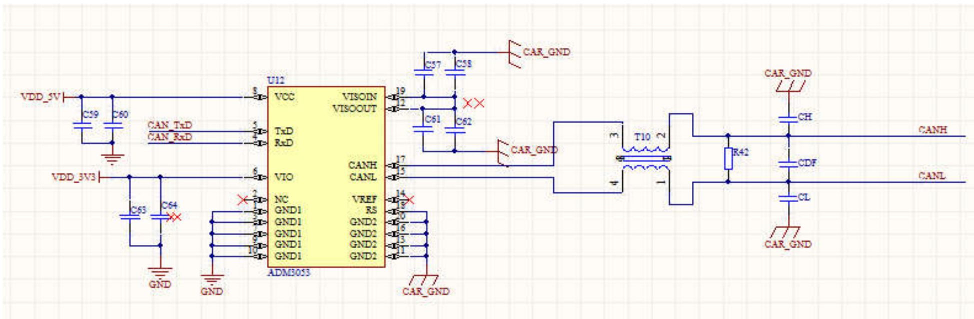

Figure7: CAN communication circuit

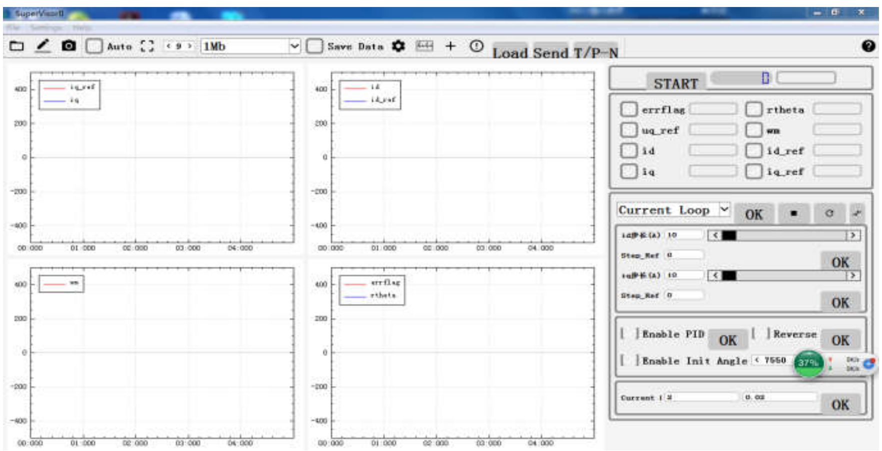

Figure8: Communication host computer display interface

2.4 Hardware protection circuit

The hardware protection includes overcurrent and drive fault signals. Once a hardware fault occurs, the D flip-flop will immediately save the fault signal, prohibit the PWM driver chip output signal, and the fault signal will enter the DSP interrupt, and notify the software to process accordingly. Hardware protection circuit shown in Fig.9.

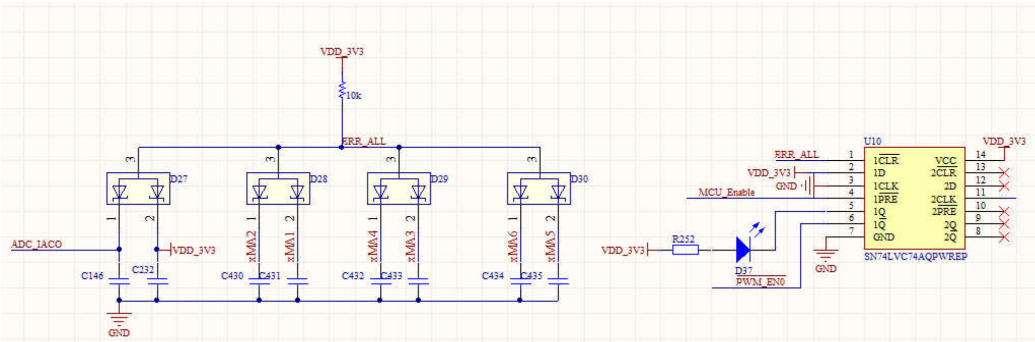

Figure9: Hardware protection circuit

3 Design result

The high power density main control board is 85mm long and 60mm wide. Figure 10 shows the PCB and physical map of the main control board.The main control board has a high-power experiment on a 80kW controller. The controller measures 158mm in length, 148mm in width, 98mm in height, 2.29L in volume and 4.5kg in weight. The permanent magnet synchronous motor model matched with the controller is EMRAX 268, the performance index is 125A/80kW/4500rpm, the internal resistance is 26mΩ, the d-axis inductance is 0.35mH, the q-axis inductance is 0.37mH, and the pole pair is 10 pairs. Figure 11 shows the control current waveform of the motor at a power of 45kW. Figure 12 shows the experimental environment. The waveform shows that the control performance of the main control board is good.

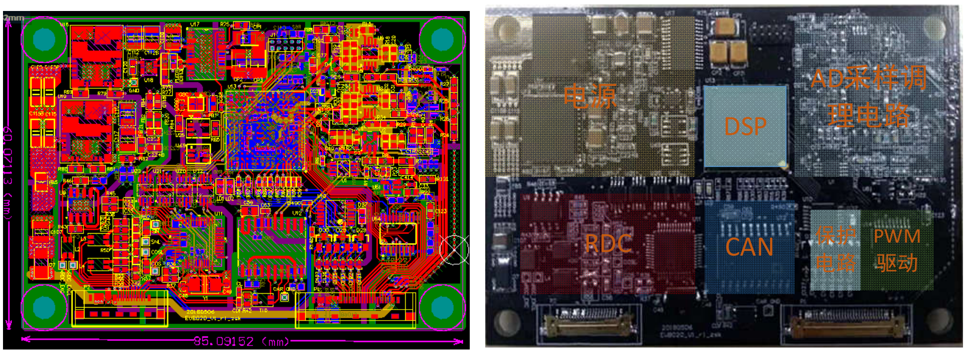

Figure10: Board PCB and physical map

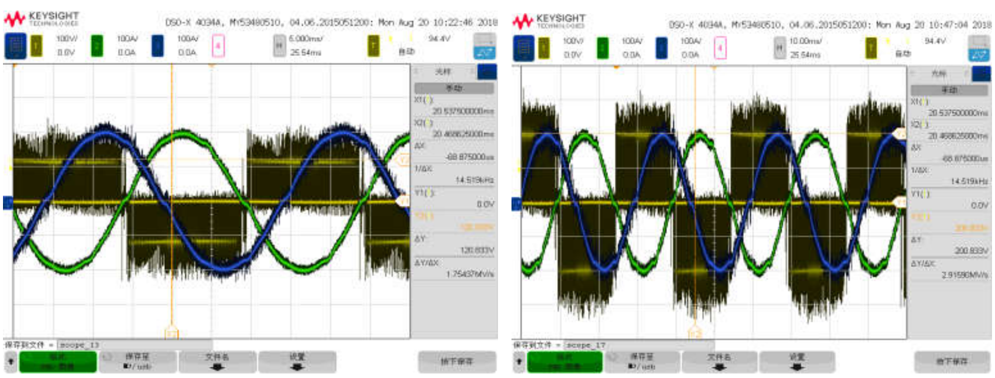

Figure11: Motor current waveform in 45kW power experiment

Figure12: Power loading experimental environment

Acknowledgments

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