R7F0C009

Power Tool BLDC Motor Driver Solution V3

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Introduction

This Application Note shows the implementation of power tool using 3-phase BLDC motor driven by 120-degree trapezoidal wave commutation. The method shown utilizes the HALL sensors in the motor to determine the motor's rotor position, and provide speed measurement.

This solution is based on Renesas Electronics' MCU R7F0C008/009 series. The microcontrollers in this series employ the RL78 core which realizes high processing performance while delivering the lowest power consumption in their class, and have enhanced computing power and peripheral functions suitable for motor control and other applications.

Target Device

MCU: R7F0C009A2DSP

Operational frequency: 24 MHz

Memory size: ROM 16 KB, RAM 1.5KB

Peripherals: Timer RD for PWM motor drive, Timer Array Unit 0 for speed measurement, A/D converter for current measurement

Contents

1. Overview

1.1 Overview

The 120-degree trapezoidal method, also referred to as 6-step, is one of the simplest method for driving 3-phase BLDC motors, which drives each winding for 120-degrees of the electrical rotation and leaves the winding un-driven for 60 degrees. Note, although the drive method is simple, this lack of drive for 60 degrees also results in higher torque ripple in the end application. The system designer must decide if this is acceptable or other drive methods should be considered.

This application note is intended to be a primer in 6-step commutation and using the R7F0C009A peripherals to drive a 3-phase BLDC motor. The main functions implemented are shown as below.

● 120 degree trapezoidal wave control;

● Close-loop control of speed;

● Three-step speed control;

● Over-current protection;

● Thermal protection.

1.2 Electrical Specifications

Size:	120mm(L)*95mm(W)		
Storage Environment:	-20 ~ 85 ^{O}C，40% ~ 95% RH		
Operation Environment:	0 ~ 70 ^{O}C，40% ~ 95% RH		
Rated Voltage:	DC 14.4V		
Rated Current:	3.5A		
Rated Power:	50W		
Speed:	High level:	0～2400 RPM	
	Middle level:	0～1800 RPM	
	Low level:	0～1100 RPM	

2. System Configuration

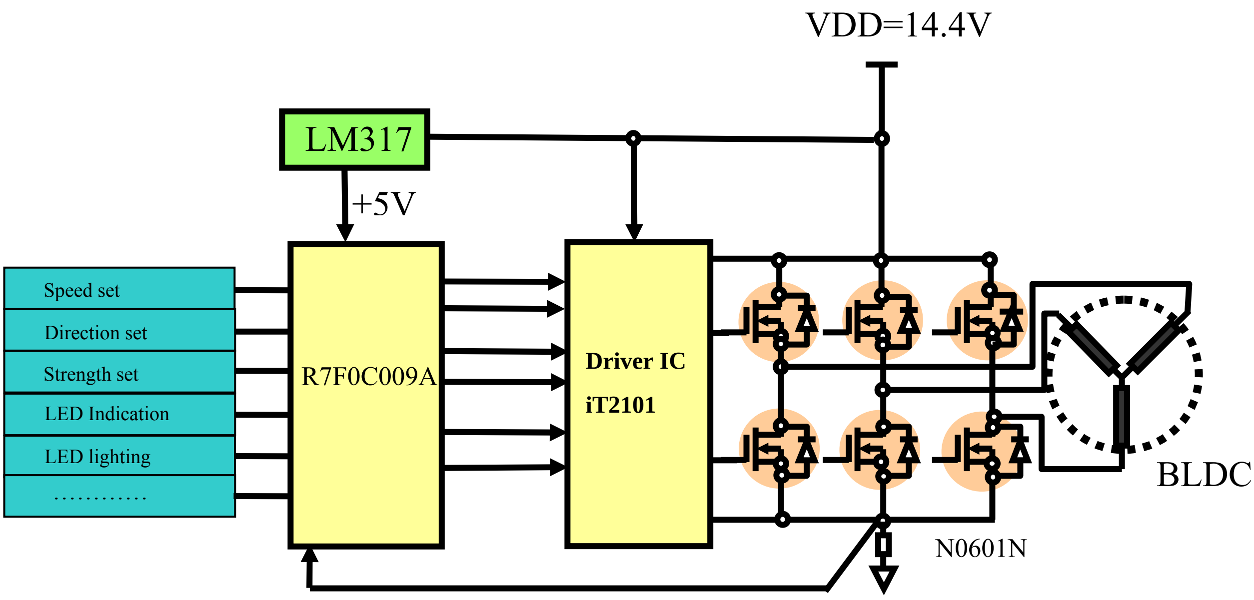


Figure 2-1 120 degree control system diagram

3. Master Controller R7F0C009A

3.1 Configuration of R7F0C009A

3.1.1 Pin of R7F0C009A

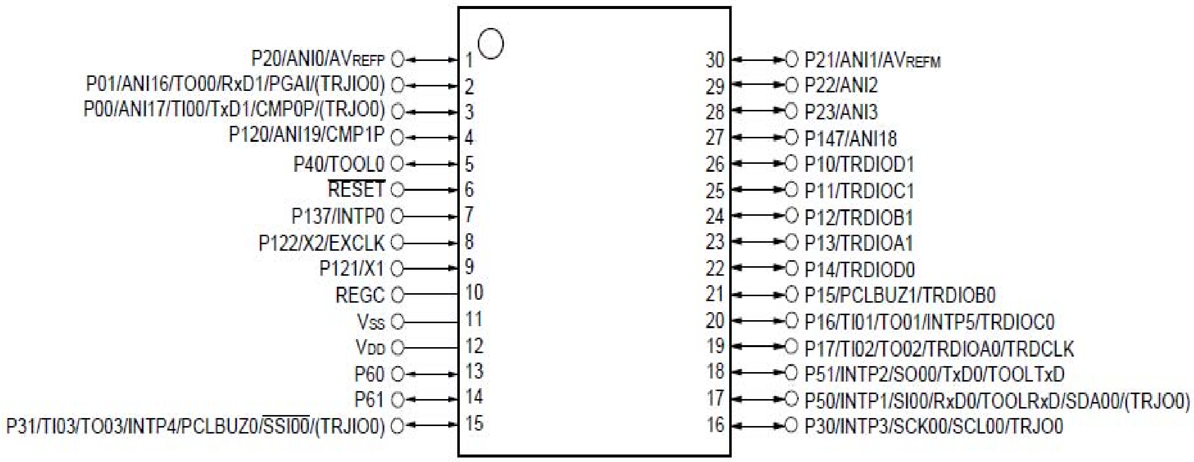


Figure 3-1 Pin of R7F0C009A

3.1.2 Structure of R7F0C009A

Table 3-1 Pin Function Configuration

Pin NO.	Pin name	Pin Function	Note
1	P20/ANI0/AVREFP	AD power reference	
2	P01/ANI16/TO00/RxD1/PGAI/(TRJIO0)	Failure indication	Output
3	P00/ANI17/TI00/TxD1/CMP0P/(TRJO0)	Tact switch	Input
4	P120/ANI19/CMP1P	Direction control	Input
5	P40/TOOL0	Program interface	Input /Output
6	RESET	Reset	Input
7	P137/INTP0	Over-current protection	Input
8	P122/X2/EXCLK	Not used	
9	P121/X1	Not used	
10	REGC	Ground via cap	
11	VSS	Ground	
12	VDD	Power	
13	P60	Strength indication 3	Output
14	P61	Strength indication 2	Output
15	P31/TI03/TO03/INTP4/PCLBUZ0/SSI00/(TRJI O0)	Strength indication 1	Output
16	P30/INTP3/SCK00/SCL00/TRJO0	HALL W	Input
17	P50/INTP1/SI00/RxD0/TOOLRxD/SDA00/(TRJ O0)	HALL U	Input
18	P51/INTP2/SO00/TxD0/TOOLTxD	HALL V	Input
19	P17/TI02/TO02/TRDIOA0/TRDCLK	LED lighting	For lighting
20	P16/TI01/TO01/INTP5/TRDIOC0	Tact switch	Input
21	P15/PCLBUZ1/TRDIOB0	Drive of U High	PWM output
22	P14/TRDIOD0	Drive of U Low	PWM output
23	P13/TRDIOA1	Drive of V High	PWM output
24	P12/TRDIOB1	Drive of W Hign	PWM output
25	P11/TRDIOC1	Drive of V Low	PWM output
26	P10/TRDIOD1	Drive of W Low	PWM output
27	P147/ANI18	AD analog input	Speed control
28	P23/ANI3	AD analog input	Over-current protection
29	P22/ANI2	AD analog input	Thermal protection
30	P21/ANI1/AVREFM	AD analog input	Battery check

4. BLDC Motor Control Theory

4.1 Basic Control Theory of BLDC

The motors used in most power tool are Brushless DC motor, which the rated power is commonly very low. External rotor structure is usually adopted to drive the power tool directly, but the power is very low because of its low rated speed, which cause the motor much bigger than other types of motor which have the same power value.

BLDC motor consists of motor, position sensor and electrical circuit. The stator is often made of several phases (such as 3 phases, four phases and five phases etc.), the rotor is consists of permanent magnet which arranged with different pole pairs. Figure 4-1 shows a three phases, two poles BLDC motor.

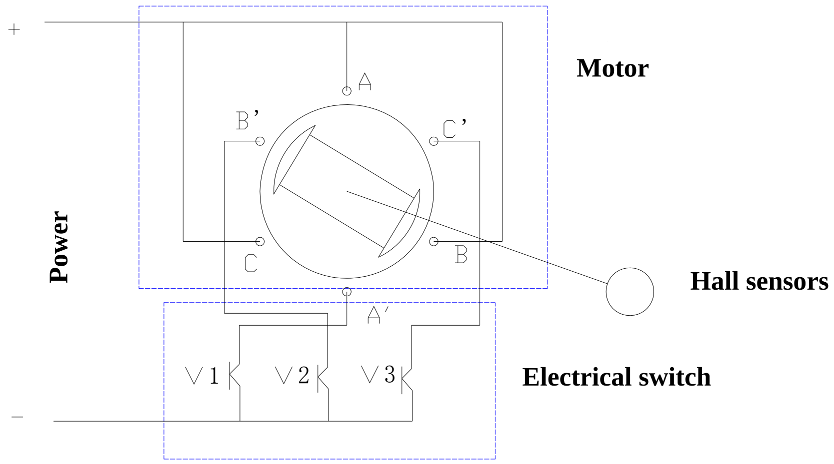


Figure 4-1 Structure of three phases, two poles BLDC motor

Three stator coils are connected with correspondent power devices in electrical circuit, A, B, C phase coils each connected with power switch V1, V2, V3. Position sensors are used to detect the rotor position.

When one of the stator coils are power on, the current will cause torque by the interaction with magnetic field caused by the rotor permanent magnetism, and the torque will cause the rotor running, the rotor position will be converted to electrical signal by position sensors to control the electrical switches, thus make the each coils of stator are switched on sequentially, the stator phase current will also change sequentially according to the position of rotor. Because of the power on sequence of electrical switches are synchronous with the rotor angle, thus cause the same effect of mechanical phase change.

Figure 4-2 shows the theory diagram of the half-bridge control of three phases, two poles BLDC motor. Photo-electric devices are use as the position sensors. The power logic unit consists of three power MOSFET. The control theory will be discussed below according to the half-bridge control.

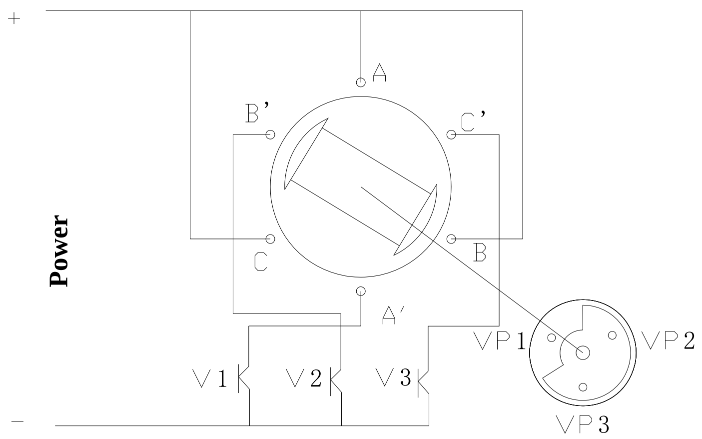


Figure 4-2 Three-phase brushless motor

The discrepancy of space position of three photo-electrical devices VP1、VP2 and VP3 are 120 degree each. Via the function of photo-electrical, the rotor position can be achieved.

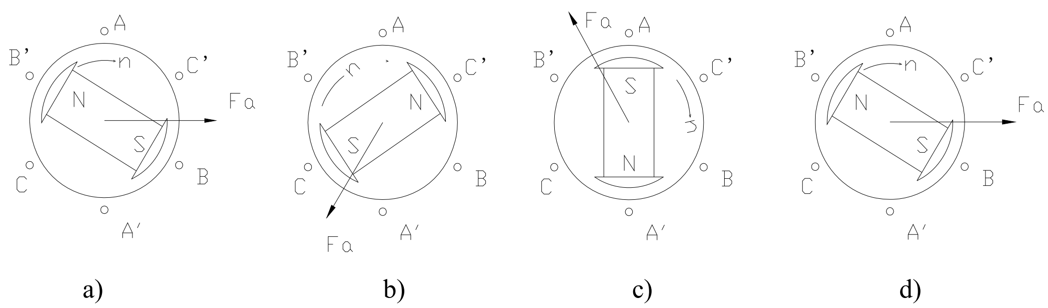


Figure 4-3 Commutation sequence and the rotation of magnetic field

The rotor position of figure 4-2 is same as that of figure 4-3a). at this position, the power MOSFET V1 is switched on and the current flows into coil A-A', the torque caused by the interaction between the coil current and rotor magnetic will make the rotor rotate as the direction shown in figure 4-3b). when the rotor locate at the position as in figure 4-3b), the power MOSFET V1 will be switched off and V2 will be switched on, the current will be changed form coil A-A' to B-B', and the rotor will continue to rotate as the direction shown in figure 4-3b). When the rotor reaches the position shown as in figure 4-3c), the power MOSFET V2 will be switched off and V3 will be switched on， the current will be flowed through C-C'， thus the rotor will continue rotate to the position shown in figure 4-3a).

With the change of position sensor signal, the stator coil will be switched on and off sequentially, then the phase current will be changed sequentially. During the phase change period, the rotating magnetic field generated by the coils of the stator is not continuous. This kind of rotating magnetic field has three state in 360 degree range, each state lasts 120 degree. The relationship between each coil and rotor magnetic field are showed in figure 4-3. Figure 4-3a）is the first state, Fa is the magnetic force generated by coil A-A', then the interaction between the coil current and rotor magnetic field will make the rotor rotate clockwise. After 120 degree， the rotor will be in the second state, the coil A-A' will be switched off and coil B-B' will be switched on， the magnetic field generated by stator coil rotate 120 degree range shown as in figure 4-3b）, and the motor rotor continue to rotate clockwise. After another

120 degree, the third state. the coil B-B' will be switched off and C-C' will be switched on, the magnetic field generated by stator coil rotate another 120 degree, shown in figure 4-3c) . It will make the rotor rotate 120 degree and then get the initial position. Figure 4-4 shows the switch on sequence of each coil.

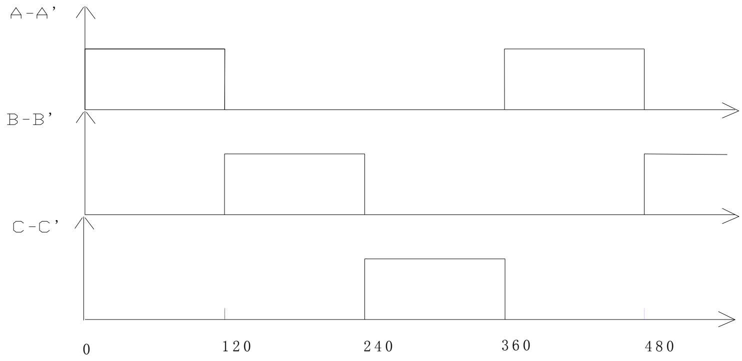


Figure 4-4 the switch on sequence of each coil

The electrical circuit of three phases, half-bridge control is simple. But the efficiency of the motor is very low because the switch on time of each phase is only 1/3 of the total time. And during the control period, the variation range of torque is very high, from $T_m/2$ to T_m. So in most circuits the three phases, full-control circuit is adopted.

4.2 Introduction of Three-phase, Full-control Theory of Y Connection Motor

Figure 4-5 show s a three-phase, full-control circuit, the motor is Y connection motor. VT1、VT2、VT3、VT4、VT5、VT6 are power MOSFET, used to control the current of each phase. The control methods include 120 degree control mode and 180 control mode.

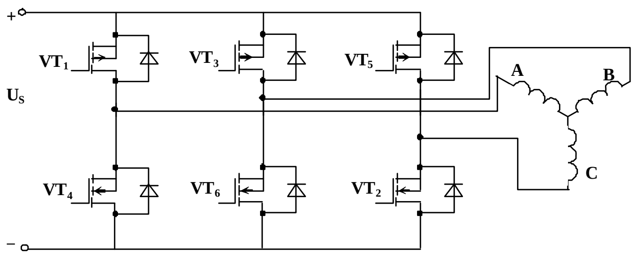


Figure 4-5 Three-phase, full-control circuit for Y connection

4.3 120 Degree Control Mode

120 degree control mode means there are two power MOSFETs are switched on at each moment, one power MOSFET will be changed to another each 1/6 period, each power MOSFET will be switched on for 120 degree. The sequence of all the power MOSFETs is VT1VT2、VT2VT3、VT3VT4、VT4VT5、VT5TF6、VT6VT1、···. When VT1 and VT2 are switched on, the current flow into coil A from VT1 and out coil C from VT2, then to the power. Assume the torque is positive when the current flows into a coil A, then the torque will be negative when the current flows out one phase, so the synthesis torque are shown in figure 4-6a), and the amplitude is $\sqrt{3}T_a$, the direction locates at the angular bisector of T_a and $-T_c$. Figure 4-6c) shows the direction of all the synthesis torque.

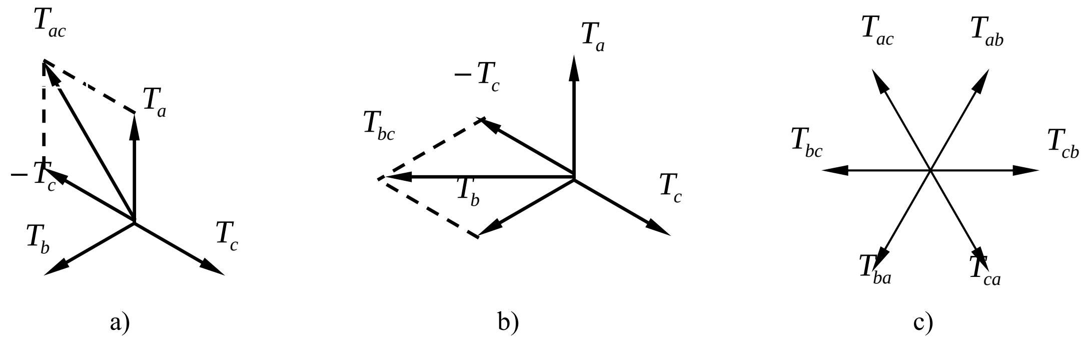


Figure 4-6 Synthesis torque of 120 degree control mode

To one BLDC motor, the synthesis torque of 120 degree control is $\sqrt{3}$ times bigger than that of half-bridge control. The output torque are shown if figure 4-7, we can see that the variation range of the synthesis torque is between $0.87T_m$ and T_m.

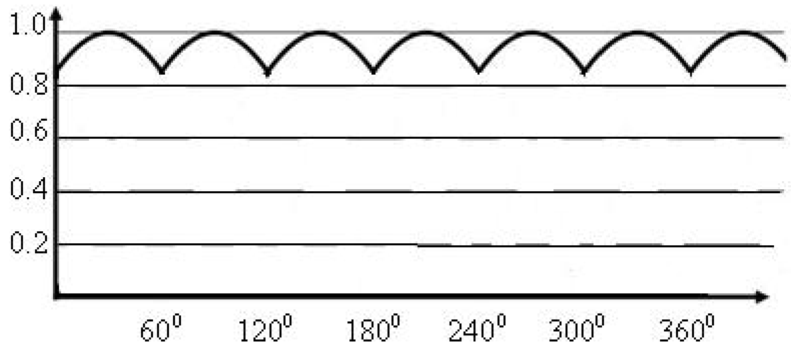


Figure 4-7 Output torque of 120 degree control

5. Hardware Structure

5.1 Power and Power Detection

Figure 5-1 shows the structure of power and power detection circuit.

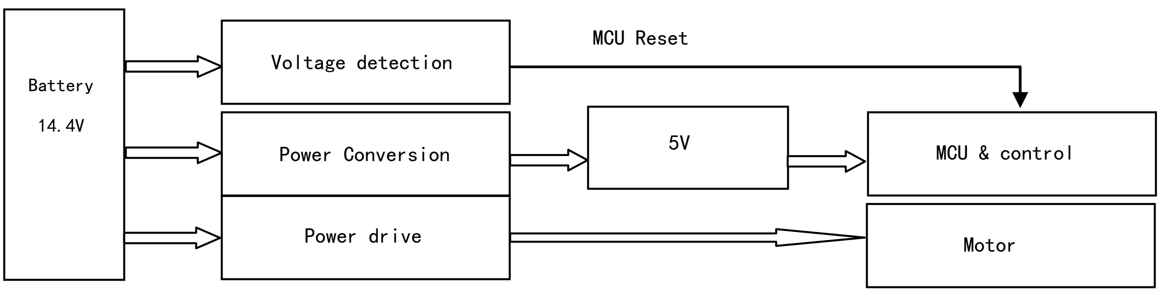


Figure 5-1 Power block diagram

5.1.1 Function Description

The power of power tool are supplied with battery, the battery in this solution is 14.4V.

14.4V voltage is supplied to driver ICs and power MOSFETs, by controlling the duty cycle of drive signal of power MOSFET, the current will be controlled thus control the speed of the motor.

To avoid the over-discharge of the battery, the voltage of the battery need to be detected and switch off the power MOSFETs when the voltage lower than 12V to protect the battery.

5V voltage is created by LM317 from 14.4V conversion, it is used to supply power to MCU and other logic control circuits, so it is also critical and need to be monitored.

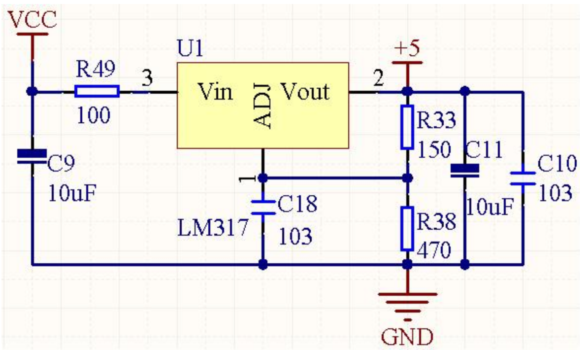


Figure 5-2 +5V creation

VCC in figure 5-2 is the battery power 14.4V, R49 is protection resister, used to reduce the voltage input to LM317T, then reduce the power consumption of LM317. LM317 is a chip used to regulate voltage, its output is set to 5V。

5.1.2 Voltage Detection Circuit

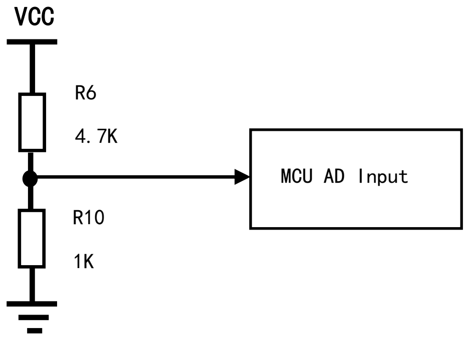


Figure 5-3 Battery voltage detection

Since the tolerance of MCU AD analog input cannot exceed 6V while VCC normally is more than 14V, we cannot monitor VCC directly, so we use a voltage divider circuit to satisfy the tolerance. The battery voltage can be monitored by sampling the divided voltage which is input to built-in AD module of MCU, in case the battery voltage is lower than the pre-set threshold value, software will execute related behavior.

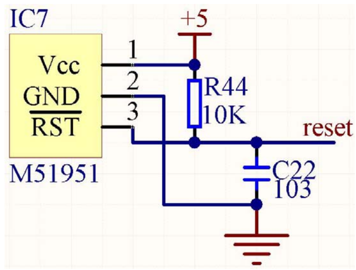


Figure 5-4 +5V detection

M51951 is integrated circuits designed for designed for detecting supply voltage and resetting logic circuits such as CPUs. Normally when +5V voltage is lower than 4.2V by due to exceptional situation during system operating, M51951 will output a valid signal (low) to reset MCU.

5.2 HALL Signal Detection

The HALL signal detection module is shown as the figure below:

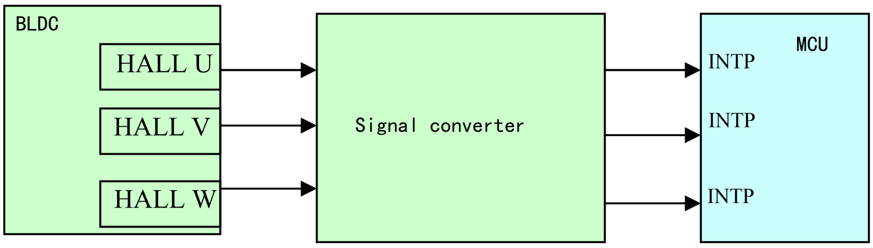


Figure 5-5 Hall input block

5.2.1 Function Description

HALL signal detection circuit used to get the rotor position, three hall signals are input to the interrupt input interface. During 180 degree control, the speed and detailed angular also can be achieved via HALL signals.

5.2.2 HALL Signal Detection Circuit

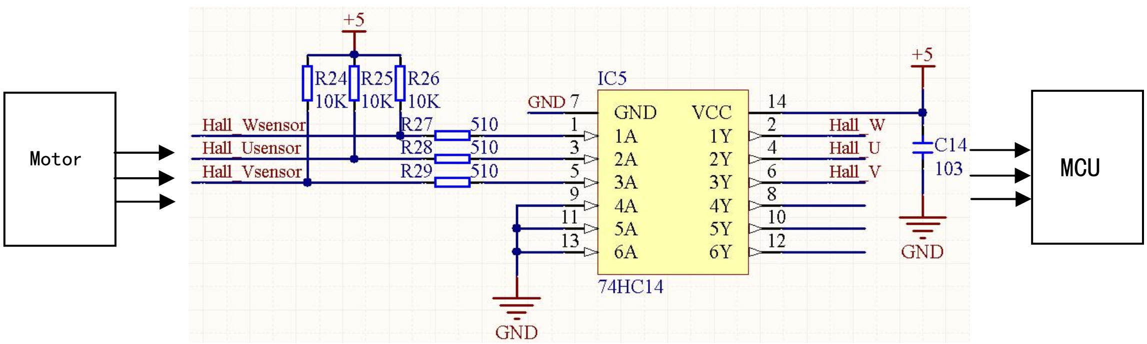


Figure 5-6 Hall input circuit

5.3 LED Indication

5.3.1 Function Description

As a part of interface between the power tool and user, LED can indicate the system operating status.

5.3.2 Circuit

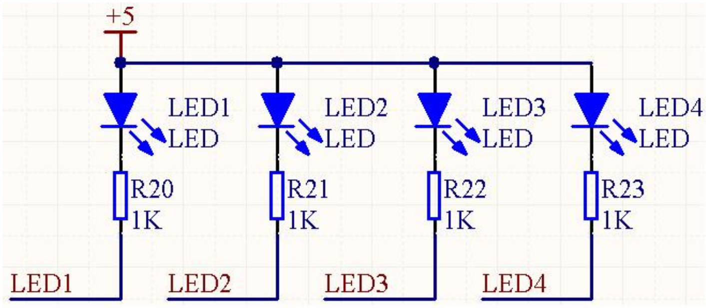


Figure 5-7 LED indication

In this application, we use 4 LEDs, LED1~LED3 are used to indicate strength level, while LED4 is used for system fault indication.

5.4 Switch Setting

5.4.1 Function Description

Several switches are used for system setting, such as strength level setting, LED lighting setting and direction setting.

5.4.2 Circuit

(1) Strength level and LED lighting setting

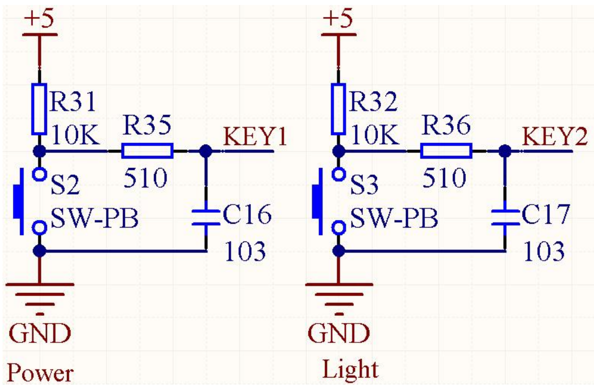


Figure 5-8 Strength level and LED lighting control

In this circuit, we use 2 tact switches: S2 and S3. S2 is used for strength level while S3 for LED lighting.

The strength level of the power tool is divided 3 levers: weak level, middle level and strong level, the strength level can be modified by pressing the S2.

We add white-LED lighting circuit in order to use the power tool in dark environment, the white-LED can be switch on or off by pressing S3.

(2) CW/CCW Rotation Control

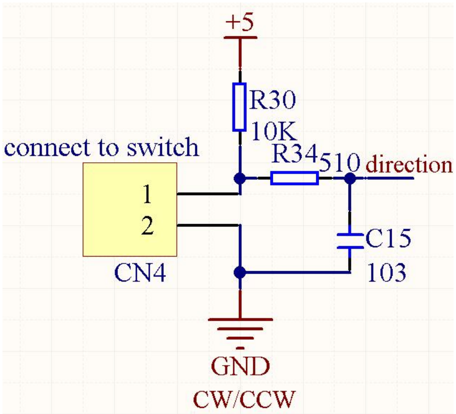


Figure 5-9 CW and CCW rotation control

CN4 is a self-locking switch and is used to control CW/CCW rotation.

5.5 Power and Power Drive

5.5.1 Function Description

Power drive circuit used to convert the control signal of MCU to drive signal of MOSFET, by controlling the state of each MOSFET, the current of the motor can be controlled.

The dead time of the two MOSFETs of each phase should be bigger than the time needed to switch off a MOSFET.

5.5.2 Circuit of Power Drive

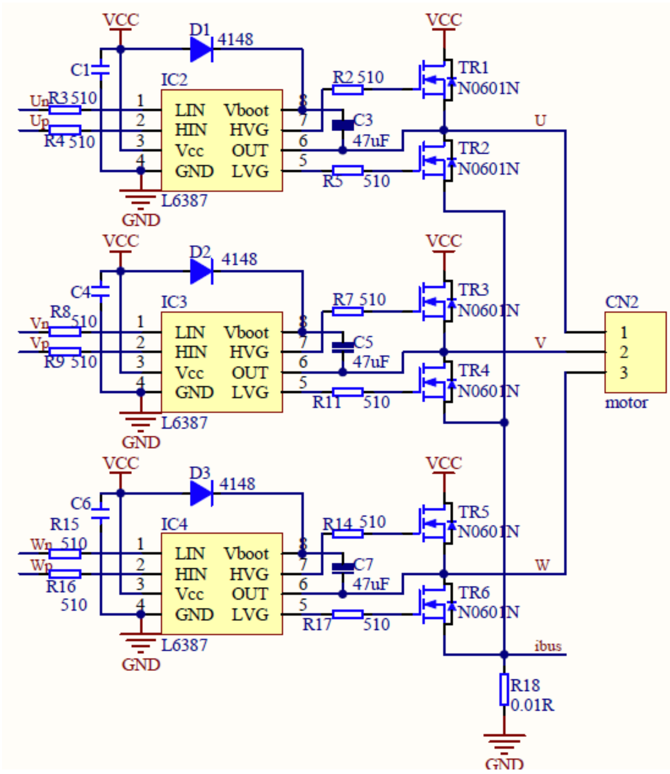


Figure 5-10 Motor driver circuit

Figure 5-10 shows the circuit of the whole 3 phase.

Compare to traditional circuit using discreet components for power drive, the above circuit use an integrated driver IC L6387, the circuit can make the system more reliable and reduce the components.

5.6 Current Sampling and Protection Circuit

5.6.1 Function Description

Current sampling circuit used to current control and current protection. Actual value of the current can be achieved by AD module, thus current close-loop control can be realized. Current protection can be realized by internal circuit.

5.6.2 Current Sampling Circuit

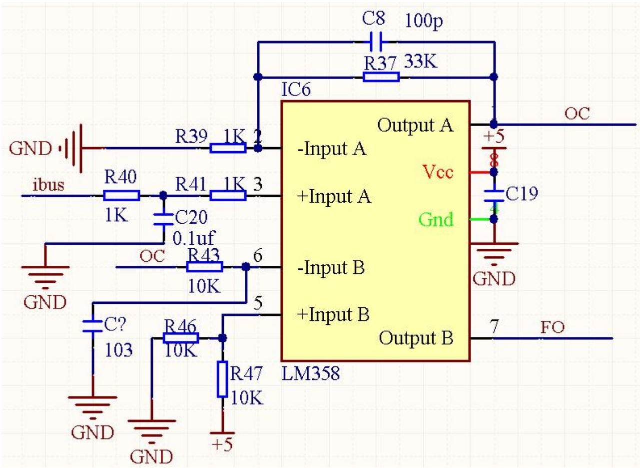


Figure 5-11 Operational amplifier circuit

R18 in figure 5-10 is a current-sampling resistor, due to the amplitude of ibus is too small to be detected by AD module in MCU, we need to use a operational amplifier LM358 to amplify ibus, the circuit as showed above. LM358 is a dual operational amplifiers, we use input A to amplify ibus, the other amplifier input B is used to be a Comparator to compare the amplified signal OC with pre-set voltage.

5.7 Thermal Protection

5.7.1 Function Description

The current consumption probably is close to 4A while the size of PCB is small, it is necessary to implement thermal protection in circuit.

5.7.2 Thermal Protection Circuit

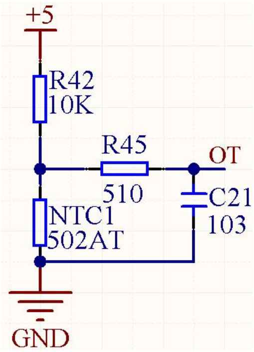


Figure 5-12 Thermal protection circuit

The figure 5-12 shows thermal protection circuit, OT is the signal which is connected to AD analog input. If the temperature of the PCB board increase, the resistance of NTC1 will decrease, thus AD module can sample the OT variation.

6. Hardware and Test Data

6.1 Specifications of BLDC Motor

The technical data of the motor are as follows:

Rated Voltage: 14.4V

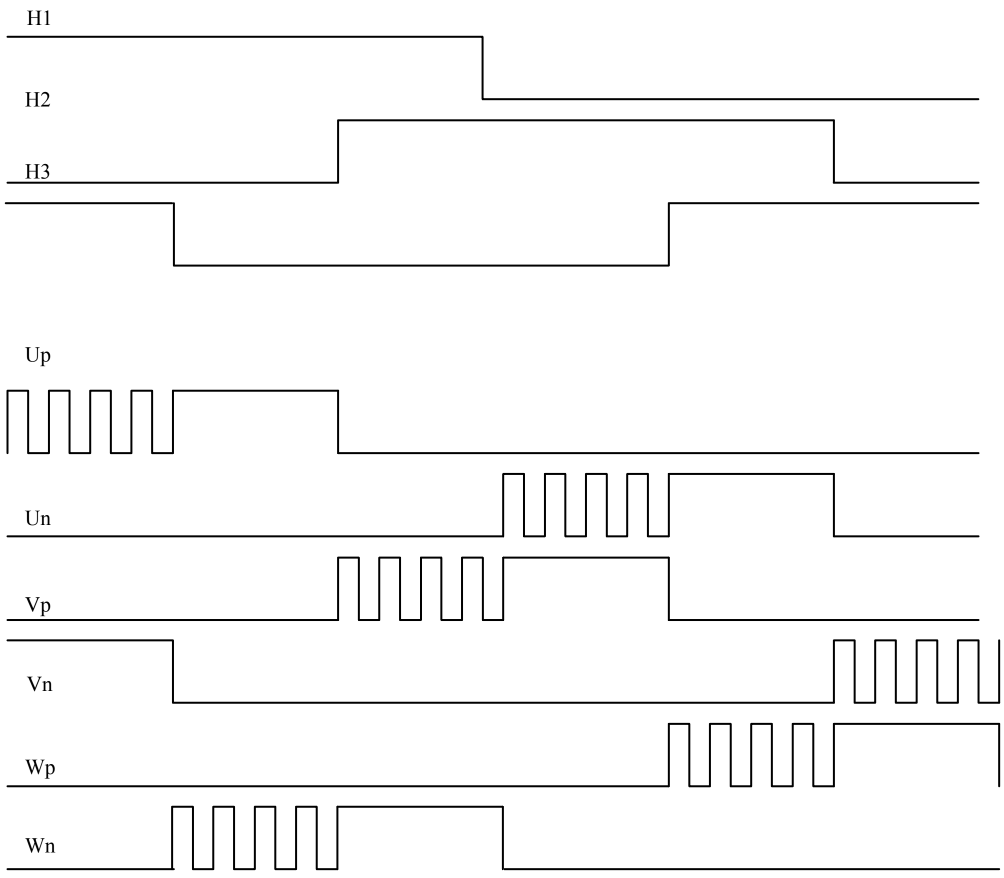
Rated Current: 3.5A

Rated Power: 50W

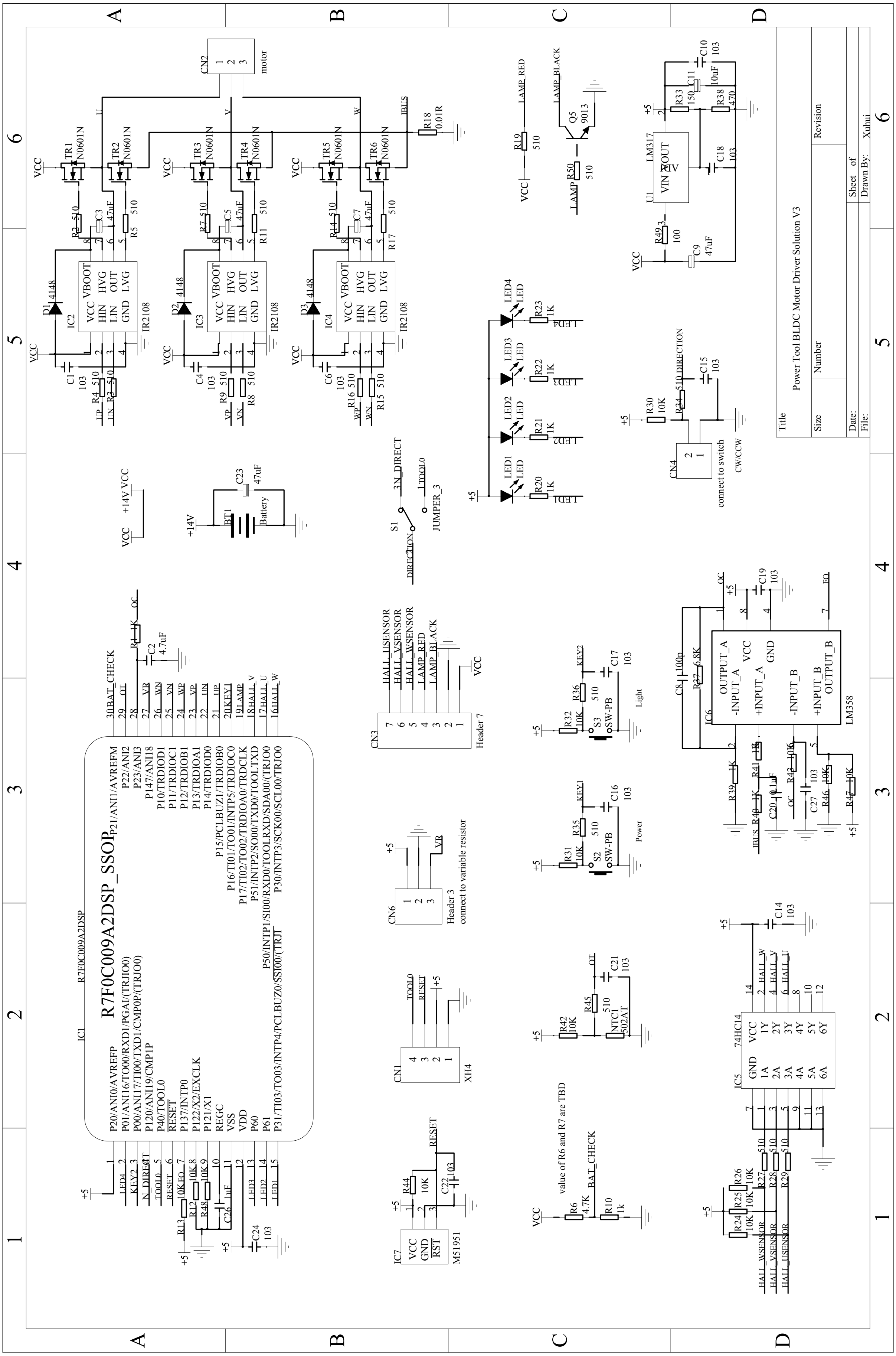
Speed: High level: 0～2400 RPM Middle level: 0～1800 RPM Low level: 0～1100 RPM

The commutation logic of the motor is shown as below.

Figure 6-1 Commutation logic



6.2 Schematics



6.3 Main Control Board

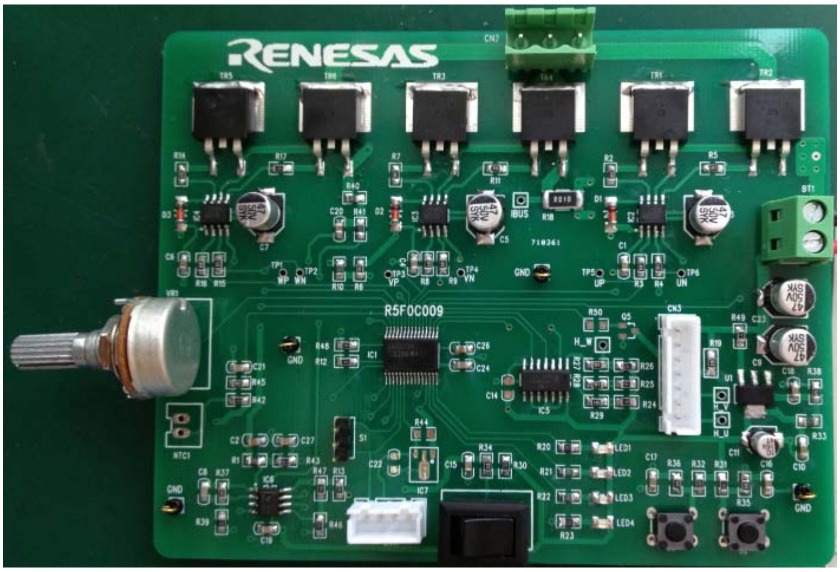


Figure 6-2 Main board of the controller

6.4 Operation Method and Test Data

6.4.1. Test Outline

Following steps should be done when run a BLDC motor by using the controller:

1) Connect all cables to the BLDC motor correctly, including hall signals, phase lines and power supply.

2) Set correct DC +14.4V on DC power supply.

3) Power on the system.

6.4.2. Test Result

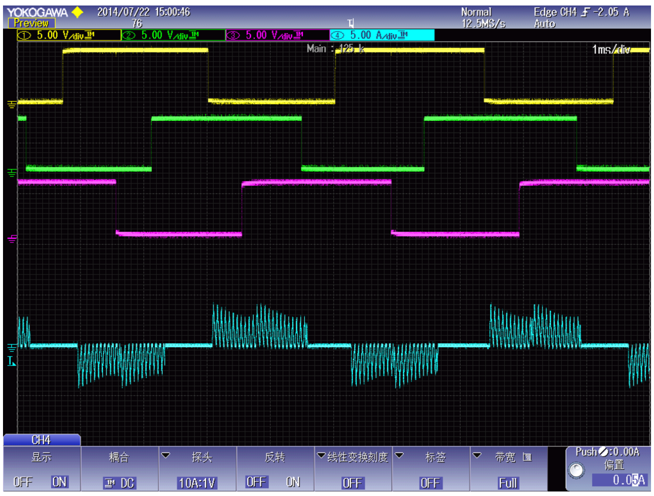


Figure 6-3 Hall signal and phase current without load (Clockwise rotation)

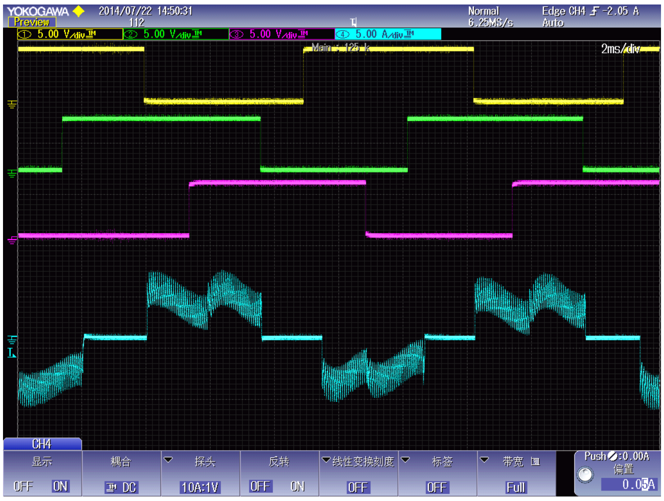


Figure 6-4 Hall signal and phase current with load (Clockwise rotation)

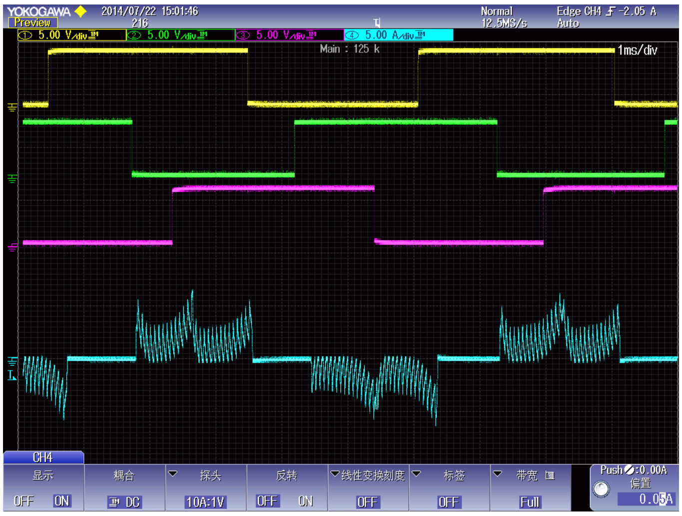


Figure 6-5 Hall signal and phase current without load (Counterclockwise rotation)

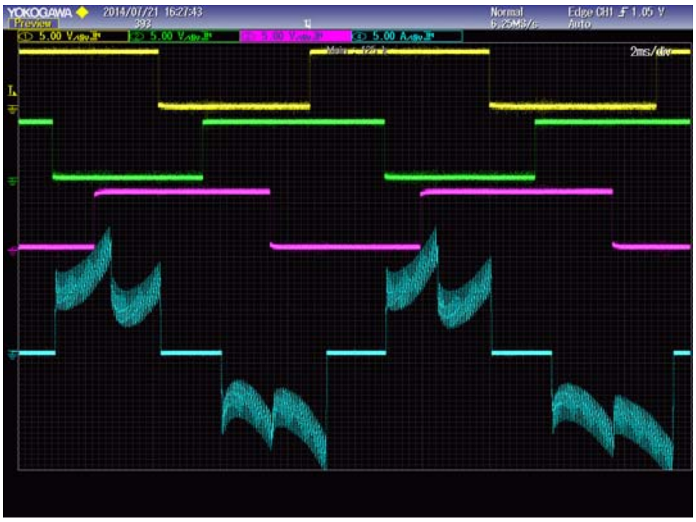


Figure 6-6 Hall signal and phase current with load (Counterclockwise rotation)

7. Software Flowchart

Software design can be divided into main function, hall interrupt, speed calculate, close-loop of speed, close-loop of current, timer interrupt, space vector calculate, over current protect function and so on.

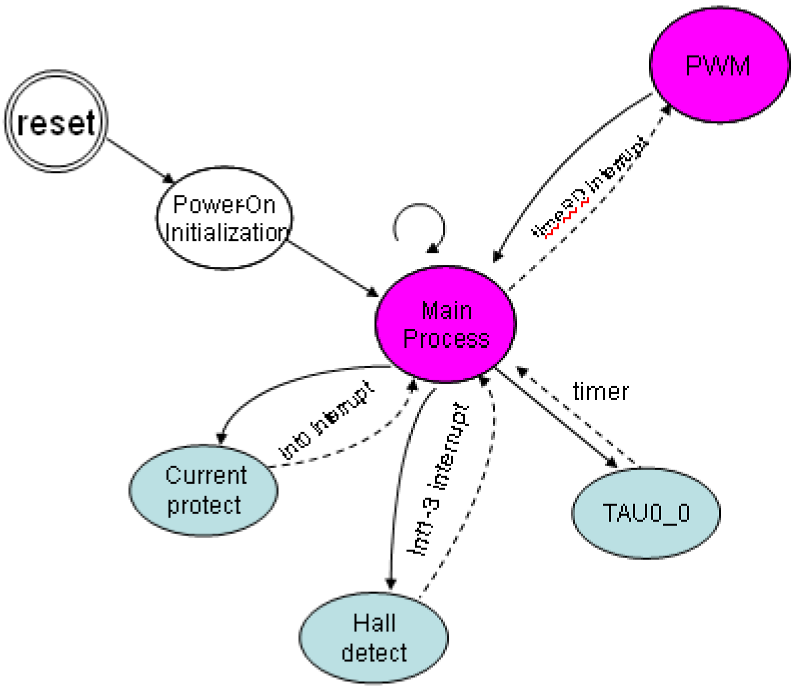


Figure 7-1 System architecture

7.1 Main Function

Figure 7-2 shows the flowchart of main function.

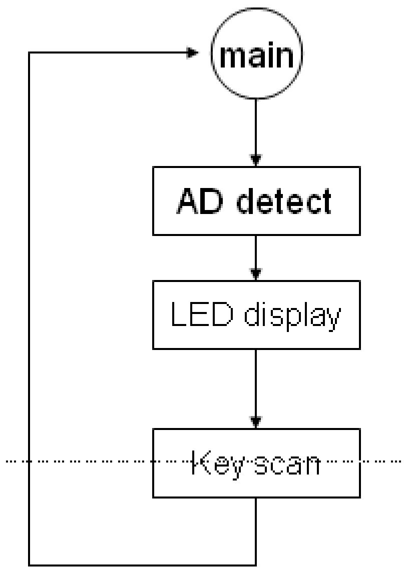


Figure 7-2 Main function flowchart

7.2 Hall Interrupt

Figure 7-3 shows the flowchart of hall interrupt.

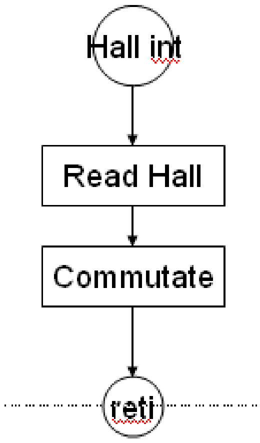


Figure 7-3 Hall interruption flowchart

7.3 Run Mode and Speed Control

Figure 7-4 shows the flowchart of speed calculation.

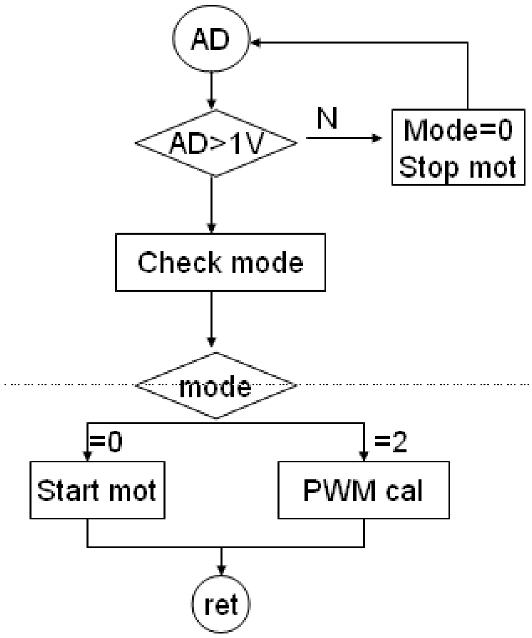


Figure 7-4 Motor operation flowchart

7.4 Current Control and Protect

Figure 7-5 shows the flowchart of current control and protect function.

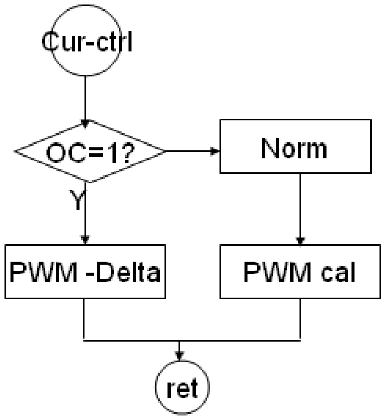


Figure 7-5 Current control flowchart

7.5 Timer Interrupt

Figure 7-6 shows the flowchart of timer interrupt.

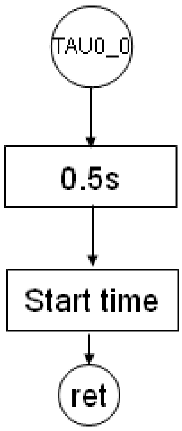


Figure 7-6 Timer control

7.6 Over Current Protect

Figure 7-7 shows the flowchart of over current function.

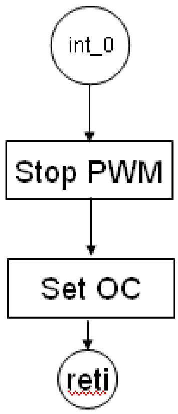


Figure 7-7 Over-current control

Website and Support

Renesas Electronics Website
http://www.renesas.com/

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Revision Record

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General Precautions in the Handling of MPU/MCU Products

The following usage notes are applicable to all MPU/MCU products from Renesas. For detailed usage notes on the products covered by this manual, refer to the relevant sections of the manual. If the descriptions under General Precautions in the Handling of MPU/MCU Products and in the body of the manual differ from each other, the description in the body of the manual takes precedence.

1. Handling of Unused Pins
   Handle unused pins in accord with the directions given under Handling of Unused Pins in the manual.
   — The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible. Unused pins should be handled as described under Handling of Unused Pins in the manual.
2. Processing at Power-on
   The state of the product is undefined at the moment when power is supplied.
   — The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the moment when power is supplied.
   In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the moment when power is supplied until the reset process is completed.
   In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the moment when power is supplied until the power reaches the level at which resetting has been specified.
3. Prohibition of Access to Reserved Addresses
   Access to reserved addresses is prohibited.
   — The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.
4. Clock Signals
   After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has stabilized.
   — When the clock signal is generated with an external resonator (or from an external oscillator) during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Moreover, when switching to a clock signal produced with an external resonator (or by an external oscillator) while program execution is in progress, wait until the target clock signal is stable.
5. Differences between Products
   Before changing from one product to another, i.e. to one with a different type number, confirm that the change will not lead to problems.
   — The characteristics of MPU/MCU in the same group but having different type numbers may differ because of the differences in internal memory capacity and layout pattern. When changing to products of different type numbers, implement a system-evaluation test for each of the products.

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Refer to "http://www.renesas.com/" for the latest and detailed information.

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