Application Note

Document No.: AN1097

APM32F035_MOTOR EVAL Senseless Vector Control Scheme

Version: V1.1

Contents

1 General Introduction

1.1 Project Overview

APM32F035 is a specialized chip launched by Geehy Semiconductor Co., Ltd. for motor control. Based on APM32F035, this design provides a dual-resistance sampling vector control scheme and uses the closed-loop sliding-mode observer estimation scheme. The detailed design specifications are shown in the table below:

Table 1 Design Specifications

Control mode	Position Sensorless Field Oriented Control (FOC)
Observer	Sliding-mode observer+PLL
PWM modulation mode	SVPWM
PWM frequency	8KHz
Motor speed	400~3000RPM (2 pairs of poles)
Starting mode	Open-loop starting
Protection function	Overvoltage, undervoltage, overcurrent, locked rotor
Code size	11Kbytes
Development software	Keil C (V5.23 version and above)

1.2 APM32F035 Chip Resources

APM32F035 is a high-performance special MCU for motor control which is based on the Arm Cortex-M0+ core, integrates the mathematical operation accelerators (Cordic, SvPWM, hardware divider, etc.) commonly used in FOC algorithms, and integrates such analog peripherals as amplifiers and comparators, as well as CAN controllers.

Table 2 Functions and Peripherals of APM32F035 Series Chip

Product		**APM32F035**	
Model		**C8T7**	**K8T7**
Package		LQFP48	LQFP32
Core and maximum working frequency		Arm® 32-bit Cortex®-M0+@72MHz	
M0CP Co-processor		1	
Flash memory (KB)		64	
SRAM(KB)		10	
Timer	32 bit/1 bit universal	1/2	
	16-bit advanced	1	

Product		APM32F035	
Model		C8T7	K8T7
	16-bit basic	2	
	24-bit counter	1	
	Watchdog (WDT)	2 (1 independent watchdog+1 window watchdog)	
	Real-time clock	1	
Communication interface	USART	2	
	SPI/I2S	1/1	
	I2C	1	
	CAN	1	
12-bit ADC	Unit	1	
	External channel	16	12
	Internal channel	3	
Comparator (COMP)		2	
Operationalamplifier (OPA)		4	2
GPIOs		42	27
Operating temperature		Ambient temperature： -40℃ to 105℃ Junction temperature： -40℃ to 125℃	
Working voltage		2.0~3.6V	

2 Hardware Introduction

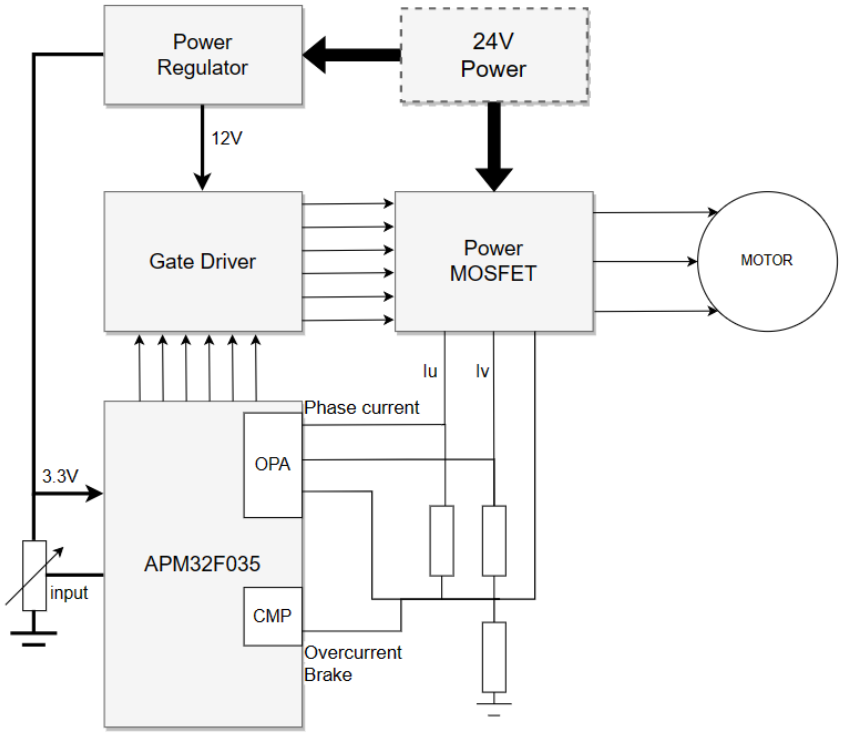
2.1 Overall Hardware Circuit

The overall hardware system is powered by an external 24V power supply and after conversion through the corresponding power step-down circuit, it outputs stable 12V, 5V, and 3.3V voltages. The 12V voltage is output to the Gate driver IC, the 3.3V voltage is output to the APM32F035 series microprocessor, and the power switch tube is directly connected to the 24V power supply. At the same time, this scheme uses a variable resistance knob to adjust the voltage input of 0~3.3V as the input end of the speed command, in order to adjust the motor speed. Users can directly adjust the input voltage by turning the variable resistor knob in actual use. When the input voltage value exceeds the starting threshold, the motor will start running, and when the voltage value is below the threshold, the motor will stop running.

After the motor is started, the APM32F035 processor can obtain the phase currents Iu, Iv, and Iw of three phases through the built-in operational amplifier and corresponding sampling circuit, and convert this data through the coordinate axis to control the torque current and phase of the motor. After the FOC control calculation link, adjust the TMR1 peripheral to output the corresponding three-way complementary PWM waves to control the switching components of the inverter.

The hardware block diagram is shown in the figure.

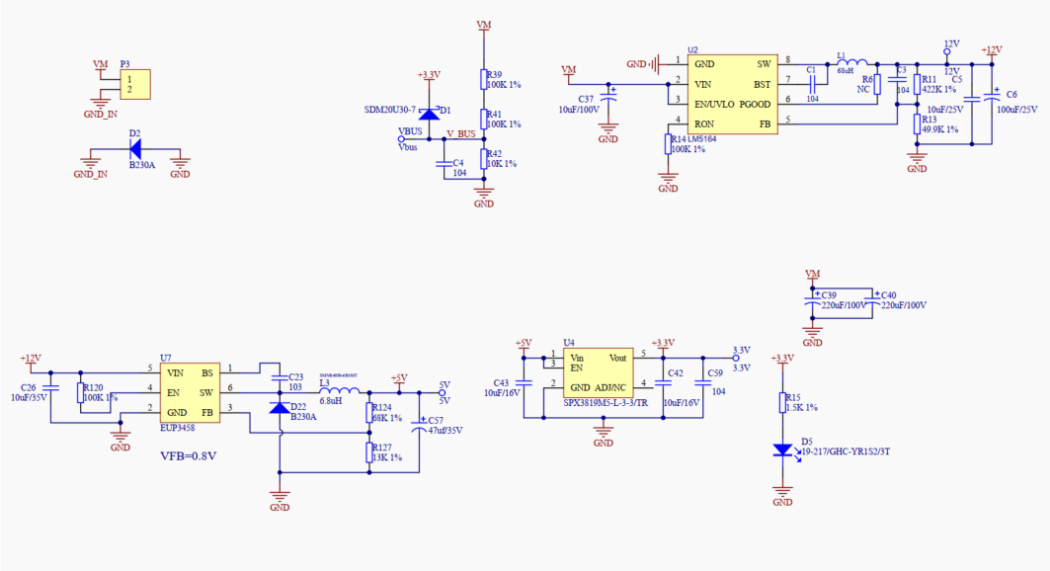
Figure 1 Hardware System Block Diagram



2.2 Interface Circuits and Settings

2.2.1 Power circuit

Figure 2 Power Circuit



As shown in the figure, supply voltage V_BUS =VM/((100K+100K+10K)/10K)=VM/21

A 12-bit ADC is adopted, and the sampling range 0-3.3V corresponds to 0-4096

Then the maximum sampling voltage corresponding to 3.3V is: VM= 3.3 *21 =69.3V

2.2.2 Phase Current Sampling Circuit

Figure 3 MOSFET Circuit

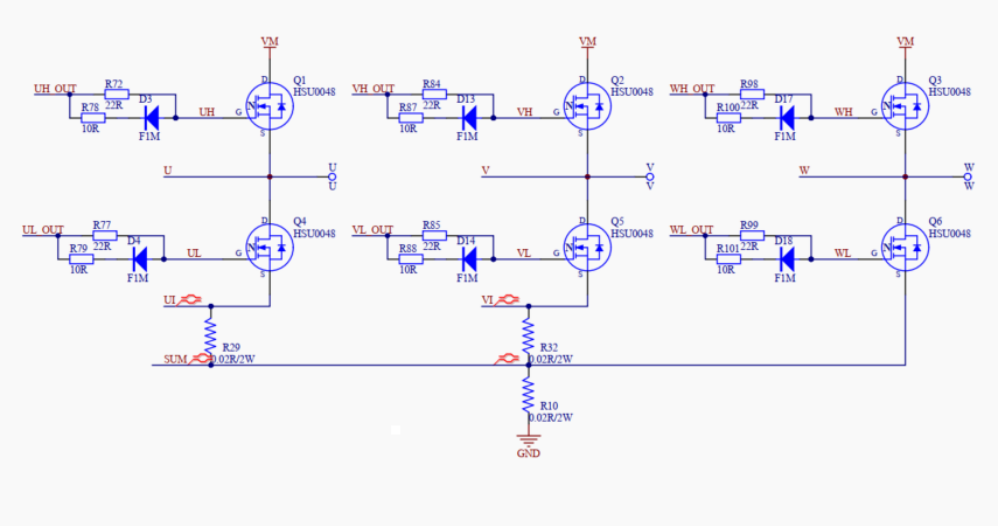
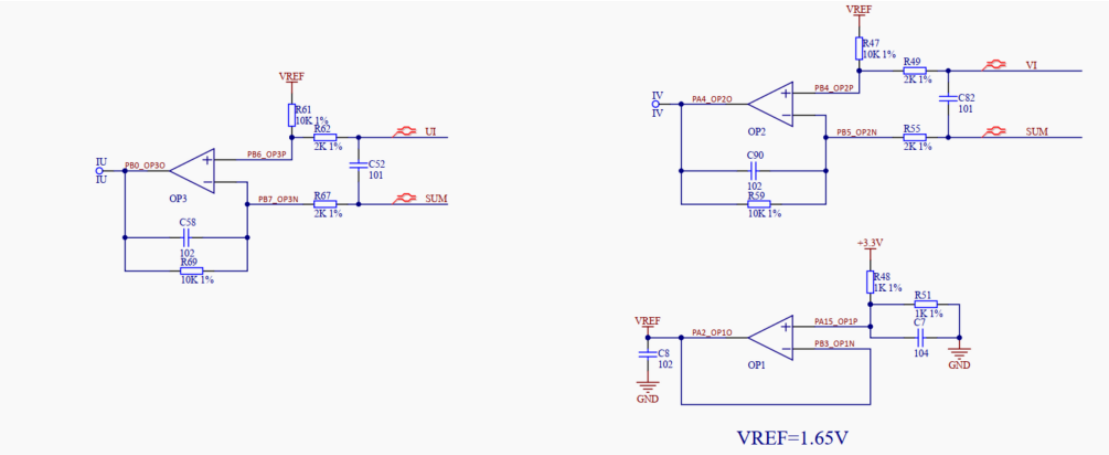


Figure 4 Current Sampling Circuit



As shown in the figure, IU=UI*5+1.65

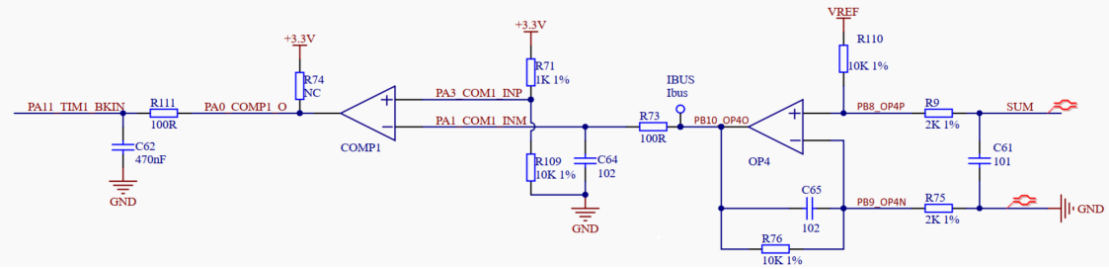
A 12-bit ADC is adopted, and the sampling range 0-3.3V corresponds to 0-4096

As shown in Figure 2-3, when the sampling resistance is selected as 0.02R,

the maximum peak-to-peak current corresponding to 3.3V is (3.3-1.65)/5/0.02=16.5A.

2.2.3 Overcurrent protection circuit

Figure 5 Overcurrent Protection Circuit



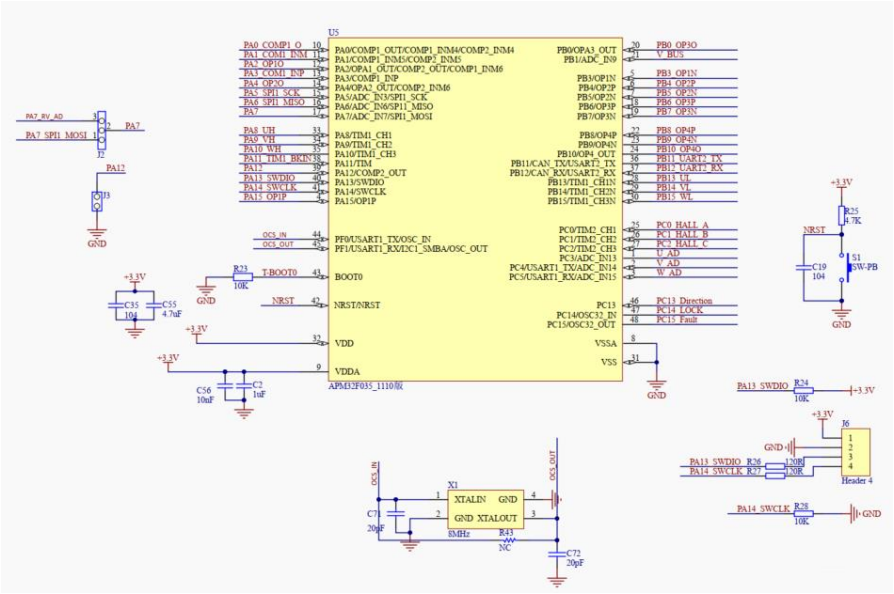
As shown in the figure, a built-in operational amplifier OPA4 is used to sample the bus current. A 12-bit ADC is adopted with a sampling range of 0-3.3V corresponding to 0-4096. From Figure 2-3, it can be seen that the sampling resistance is 0.02R;

The output end of OPA4 is used as the reverse input end of COMP1, and resistance voltage division is adopted at the forward input end. Through simple calculation, it can be concluded that the input is 3V;

Then the maximum current corresponding to 3V is (3-1.65)/5/0.02=13.5A.

2.2.4 Minimum system circuit

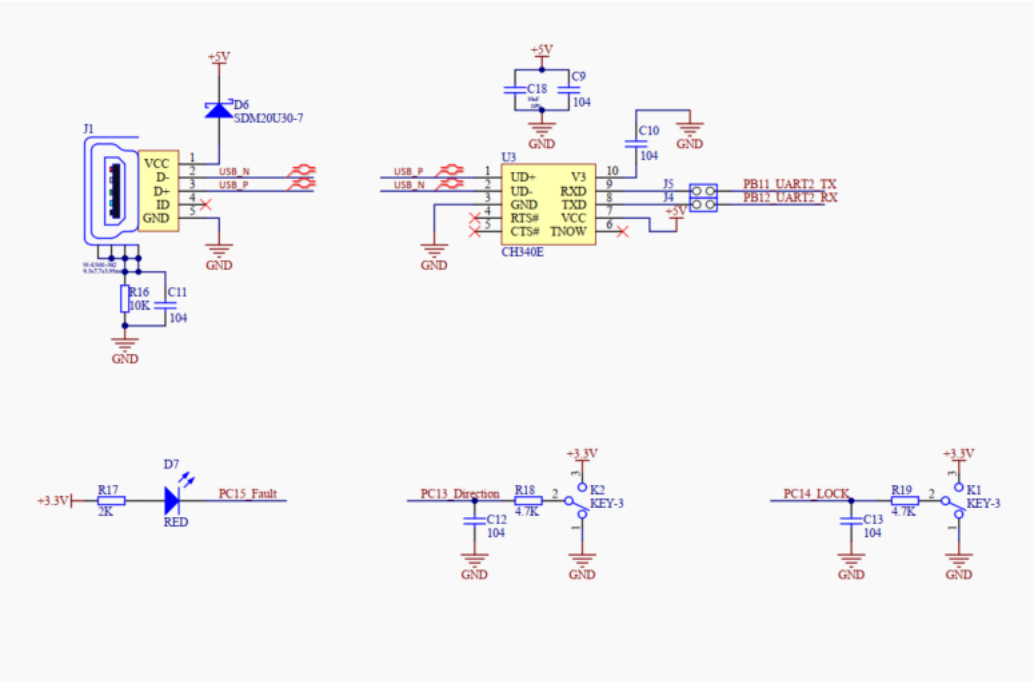
Figure 6 Minimum System Circuit



As shown in the figure, the utilization of APM32F035 MOTOR EVAL V1.0 board hardware interface resources is described in the above figure. The external crystal oscillator input of HSE is 8MHz, and SWD burning interface is adopted for burning.

2.2.5 Communication Interface and Button Circuit

Figure 7 Communication Interface and Button Circuit



As shown in the figure, a USB-to-serial port and a fault indicator light are reserved in the APM32F035 MOTOR EVAL V1.0 board hardware for debugging by developers; the two buttons are responsible for implementing the functions of controlling the running direction of the motor and locking.

2.3 Physical System Hardware

The picture of the system is shown in the figure, and it mainly includes the following four interfaces:

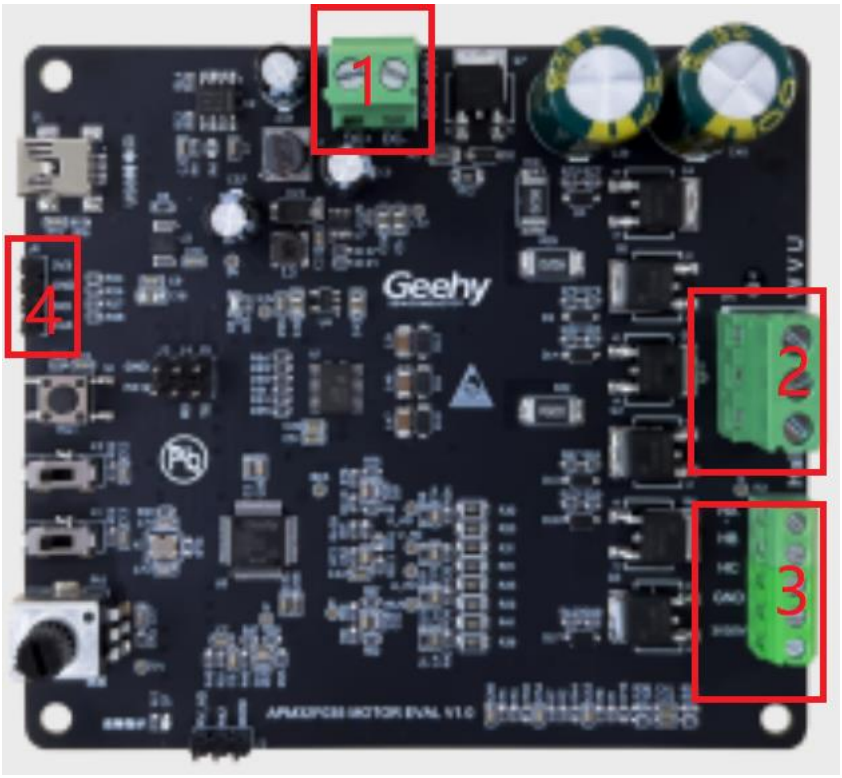
(1) Power input interface (connect to 24V; pay attention to positive and negative poles)

(2) Three phase motor interface (phase sequence only affects the direction of rotation)

(3) HALL input interface

(4) SWD debugging interface

Figure 8 Hardware Picture



3 Software Introduction

3.1 Overall Program Architecture

The overall code architecture of this project can be divided into four layers: user layer, peripheral driver layer, motor control driver layer, and motor algorithm layer. The specific functional descriptions are as follows:

3.1.1 USER Layer

main.c: The main function entry is responsible for switching of motor initialization parameters, underlying peripherals, interrupt priority, while cycle, and low-speed state machine loop;

apm32f035_int.c: All interrupt handling functions, mainly including TMR1 interrupt function and ADC interrupt handler function;

user_function.c: Includes initialization configuration, parameter reset, and other handler functions of motor parameters;

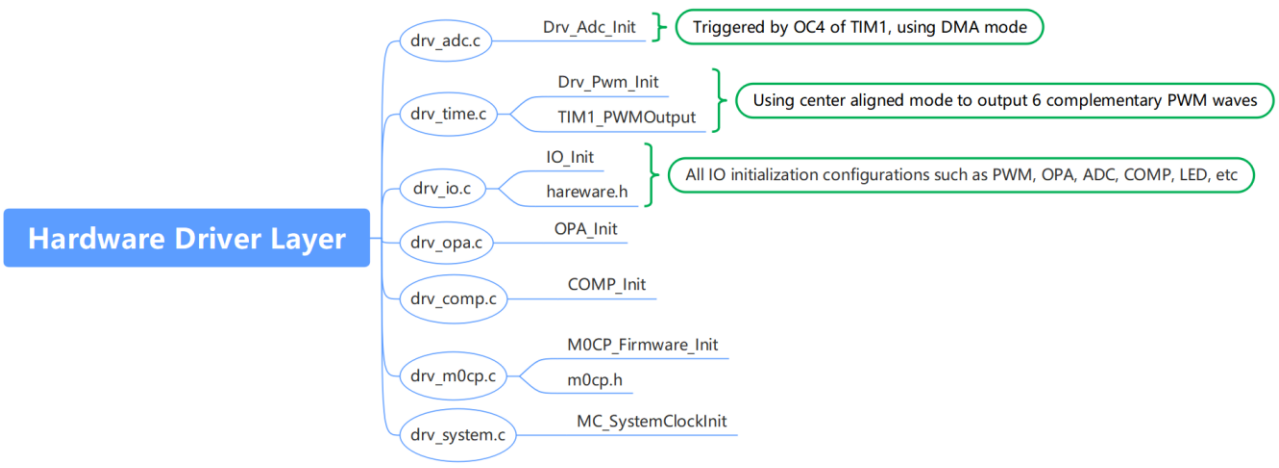
parameter.h: Includes all required configuration parameter information;

board.c: Includes initialization configuration functions of board-level underlying peripheral.

3.1.2 Peripheral Driver Layer (HARDWARE Layer)

The peripheral driver layer is mainly responsible for the peripheral driver functions and configuration of the APM32F035 chip, mainly including GPIO, PWM, ADC, OPA, COMP and M0CP coprocessors, as shown in the following figure.

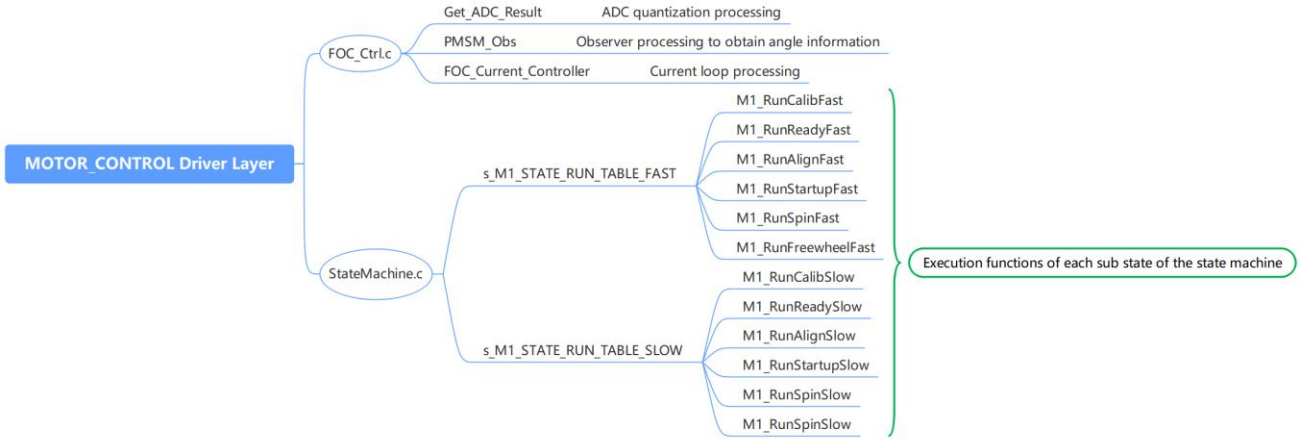
Figure 9 Peripheral Driver Layer



3.1.3 Motor Control Drive Layer (MOTOR_CONTROL Layer)

The motor control driver layer is mainly responsible for the control run logic and core processing algorithm call of the motor, as shown in the following figure.

Figure 10 Motor Control Driver Layer



3.1.4 Geehy Motor Algorithm Layer (Geehy_MCLIB Layer)

The motor algorithm layer includes coordinate transformation, vector control and other related functions, as well as math libraries, sliding-mode observer and other library functions.

3.2 Introduction to State Machine

In this case, the structure of embedding the sub-state machine into the main state machine is adopted, as shown below:

Four main states: INIT, STOP, FAIL, and RUN;

The six RUN sub-states of the main state are **run calib, run-ready, run-align, run-startup, run-spin, and run-freewheel**.

The main state machine is described below:

Fault: When an error occurs in the system, it will remain in this state until the error flag bit is cleared;

Then after delay for a period of time, it will jump from the Fault state to the STOP state and wait for the start command.

Init: This main state executes variable initialization.

Stop: The system waits for the speed command after completing initialization. In this state, the PWM output is turned off.

Run: In the running state, if a Stop command is issued, the system will stop running.

When the system is running in the Run state, its sub-states will be called and executed.

Run-Calib: The current biased ADC self-calibration function can be executed. After this state is executed, the system will switch to the Ready state and disable the PWM output.

Ready: Enable PWM output, synchronously sample the current, and conduct abnormal state inspection.

Align: Execute sampling current, call pre-positioning algorithm, and update the PWM. Execute the state within the specified time, and the system will switch to the Startup sub-state and sample the DC bus voltage for filtering.

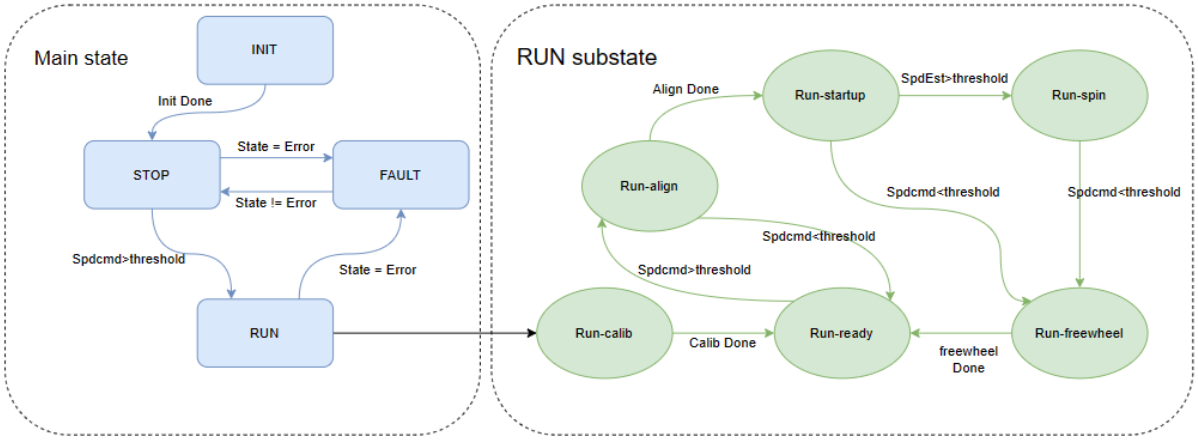
Startup: Sample the current, use an open-loop starting motor, and call the observer to estimate the rotor speed and position, call the corresponding algorithm, and update the PWM. If the motor is started successfully, the system will spin the sub-state and sample the DC bus voltage for filtering.

Spin: Sample the current, call the observer to estimate the rotor speed and position, call the corresponding algorithm, update the PWM, and the motor starts to switch to closed-loop operation.

Freewheel: Enable PWM output and stop the machine through shorting the brake. Due to rotor inertia, the state can be switched only after the motor stops running and further switched to Ready state. If an error occurs, the system will enter the Fault state.

To sum up, the state machine flowchart of the system is shown in the figure below.

Figure 11 State Machine Flowchart



3.3 Top-layer Peripheral Configuration

3.3.1 PWM Output Configuration

void Drv_Pwm_Init(uint16_t u16_Period,uint16_t u16_DeadTime)

(1) The general configuration of PWM is as follows:

Set the PWM clock frequency division to 1, select the center-aligned mode 2, and set the repeat counter to 1, as shown in the figure below.

Figure 12 General Configuration of PWM

```
/* Time Base configuration ,init time1 freq*/
TIM_TimeBaseInitStructure.period          = u16_Period;
TIM_TimeBaseInitStructure.div             = 0;
TIM_TimeBaseInitStructure.counterMode     = TMR_COUNTER_MODE_CENTERALIGNED2;
TIM_TimeBaseInitStructure.clockDivision   = TMR_CKD_DIV1;
TIM_TimeBaseInitStructure.repetitionCounter = 1;
TMR_ConfigTimeBase(TMR1, &TIM_TimeBaseInitStructure);
```

Figure 13 Center-aligned Mode Selection

Center-Aligned Mode Select

In the Center-aligned mode, the counter counts up and down alternately; otherwise, it will only count up or down. Different Center-aligned modes affect the timing of setting the output comparison interrupt flag bit of the output channel to 1; when the counter is disabled (CNTEN=0), select the Center-aligned mode.

00: Edge-alignment mode

01: Center-aligned mode 1 (the output comparison interrupt flag bit of output channel is set to 1 when counting down)

10: Center-aligned mode 2 (the output comparison interrupt flag bit of output channel is set to 1 when counting up)

11: Center-aligned mode 3 (the output comparison interrupt flag bit of output channel is set to 1 when counting up/down)

(2) PWM Output Status Configuration

Set the output status of upper and lower tubes of PWM and enable the configuration of PWM output of the upper and lower tubes to be effective,

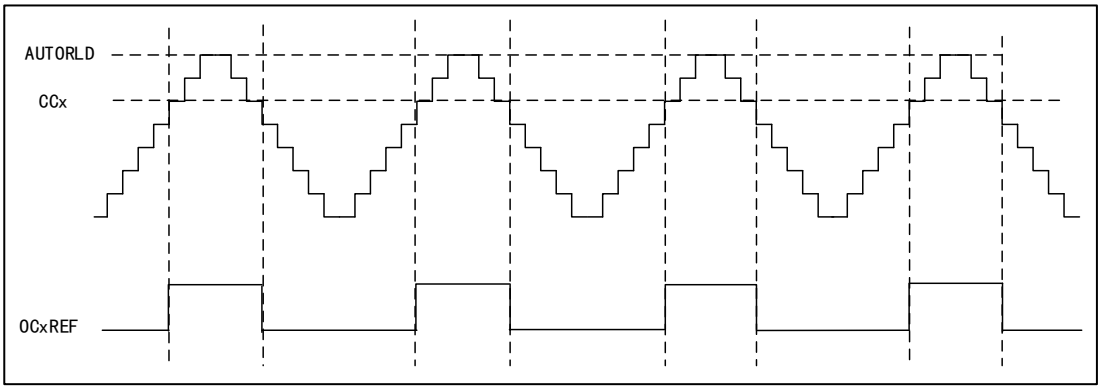
configure the enabled brakes, configure the brake input polarity, and disable automatic recovery of brake hardware.

Figure 14 PWM Output Status Configuration

```
/* Automatic Output enable, Break, dead time and lock configuration*/
TIM_BDTRInitStructure.RMOS_State       = TMR_RMOS_STATE_ENABLE;
TIM_BDTRInitStructure.IMOS_State       = TMR_IMOS_STATE_ENABLE;
TIM_BDTRInitStructure.lockLevel        = TMR_LOCK_LEVEL_OFF;
TIM_BDTRInitStructure.deadTime         = u16_DeadTime;//
/**
  * Brake configuration: enable brake
  * Brake input polarity: active in low level
  * Auto output enable configuration: Disable MOE bit hardware control
  */
TIM_BDTRInitStructure.breakState       = TMR_BREAK_STATE_ENABLE;
TIM_BDTRInitStructure.breakPolarity    = TMR_BREAK_POLARITY_LOW;
TIM_BDTRInitStructure.automaticOutput  = TMR_AUTOMATIC_OUTPUT_DISABLE;
TMR_ConfigBDT(TMR1, &TIM_BDTRInitStructure);

/*pwm driver set, channel 1,2,3,4set pwm mode*/
TIM_OCInitStructure.OC_Mode        = TMR_OC_MODE_PWM2;
TIM_OCInitStructure.OC_OutputState = TMR_OUTPUT_STATE_ENABLE;  //TMR_OUTPUT_STATE_DISABLE;
TIM_OCInitStructure.OC_OutputNState= TMR_OUTPUT_NSTATE_ENABLE; //TMR_OUTPUT_NSTATE_DISABLE;
TIM_OCInitStructure.Pulse          = 0;
TIM_OCInitStructure.OC_Polarity    = TMR_OC_POLARITY_HIGH;
TIM_OCInitStructure.OC_NPolarity   = TMR_OC_NPOLARITY_HIGH; //
TIM_OCInitStructure.OC_Idlestate   = TMR_OCIDLESTATE_RESET;  // TMR_OCIDLESTATE_SET; //
TIM_OCInitStructure.OC_NIdlestate  = TMR_OCNIDLESTATE_RESET; // TMR_OCNIDLESTATE_SET;//
```

Figure 15 Timing Diagram of PWM2 Center-aligned Mode



In count-up mode, when TMR1_CNT<TMR1_CCR1, Channel 1 is invalid level; otherwise it is valid level;

In count-down mode, when TMR1_CNT>TMR1_CCR1, Channel 1 is valid level; otherwise it is invalid level.

3.3.2 ADC Configuration

void Drv_Adc_Init(void)

1. ADC underlying configuration

DMA mode is adopted, and the quantized data of ADC is directly transported to the ADC_ConvertedValue array for storage. The ADC trigger condition uses CC4 of TMR1 as the trigger source, to enable ADC and configure ADC interrupt priority and its enable. Details are shown below:

Figure 16 ADC Underlying Configuration

```
void Drv_Adc_Init(void)
{
    ADC_Config_T    ADC_InitStructure;
    DMA_Config_T    DMA_InitStructure;
    DMA_InitStructure.peripheralAddress   = (uint32_t)&(ADC->DATA);//
    DMA_InitStructure.memoryAddress       = (uint32_t)&ADC_ConvertedValue[0];
    DMA_InitStructure.direction           = DMA_DIR_PERIPHERAL; //
    DMA_InitStructure.bufferSize          = 4;//TOTAL_CHANNEL; //
    DMA_InitStructure.peripheralInc       = DMA_PERIPHERAL_INC_DISABLE; //
    DMA_InitStructure.memoryInc           = DMA_MEMORY_INC_ENABLE;//DMA_MEMORY_INC_ENABLE;
    DMA_InitStructure.peripheralDataSize  = DMA_PERIPHERAL_DATASIZE_HALFWORD ;
    DMA_InitStructure.memoryDataSize      = DMA_MEMORY_DATASIZE_HALFWORD ;
    DMA_InitStructure.circular            = DMA_CIRCULAR_ENABLE  ;
    DMA_InitStructure.priority            = DMA_PRIORITY_LEVEL_VERYHIGH ;
    DMA_InitStructure.memoryTomemory      = DMA_M2M_DISABLE;

    DMA_Config(DMA_CHANNEL_1, &DMA_InitStructure);
    DMA_Enable(DMA_CHANNEL_1);
    ADC_ClockMode(ADC_CLOCK_MODE_ASYNCLK);
    ADC_ConfigStructInit(&ADC_InitStructure);
    ADC_InitStructure.convMode      = ADC_CONVERSION_SINGLE;
    ADC_InitStructure.scanDir       = ADC_SCAN_DIR_UPWARD;
    ADC_InitStructure.extTrigConv1  = ADC_EXT_TRIG_CONV_TRG1;  //  timer1 CC4
    ADC_InitStructure.extTrigEdge1  = ADC_EXT_TRIG_EDGE_RISING;
    ADC_InitStructure.dataAlign     = ADC_DATA_ALIGN_RIGHT;
    ADC_InitStructure.resolution    = ADC_RESOLUTION_12B;
    ADC_Config(&ADC_InitStructure);
    ADC_ConfigChannel(ADC_CHANNEL_2 | ADC_CHANNEL_8 | ADC_CHANNEL_7 | ADC_CHANNEL_9 ,ADC_SAMPLE_TIME_1_5);
    ADC->CFG1_B.OVRMAG = 1;
    ADC_EnableInterrupt(ADC_INT_CS);
//=========================ADC        ================================================
    NVIC_EnableIRQ(ADC_COMP_IRQn);
    NVIC_SetPriority(ADC_COMP_IRQn,0);
    ADC_DMARequestMode(ADC_DMA_MODE_CIRCULAR);
    ADC_EnableDMA();
    ADC_Enable();
    ADC_StartConversion();//
}
```

3.3.3 OPA and COMP Underlying Configuration

1. OPA underlying configuration

To configure the underlying configuration of OPA, first configure the OPA pin, DISABLE the operational amplifier OPA, configure to use an external resistor network, and then ENABLE it, as shown in the figure below;

Figure 17 OPA Underlying Configuration

```
void OPA_Init(void)
{
    OPA_Disable(OPA1);
    OPA_Disable(OPA2);
    OPA_Disable(OPA3);
    OPA_Disable(OPA4);
    OPA_SelectGainFactor(OPA1,OPA_GAIN_FACTOR_0);
    OPA_SelectGainFactor(OPA2,OPA_GAIN_FACTOR_0);
    OPA_SelectGainFactor(OPA3,OPA_GAIN_FACTOR_0);
    OPA_SelectGainFactor(OPA4,OPA_GAIN_FACTOR_0);
    OPA_Enable(OPA1);
    OPA_Enable(OPA2);
    OPA_Enable(OPA3);
    OPA_Enable(OPA4);
}
```

1. COMP underlying configuration

COMP is used for overcurrent anomaly detection. To configure the underlying configuration of COMP, first configure the COMP pin, set the COMP output to the BKIN connected to TMR1, set the output reverse, and trigger the BKIN of TMR1 at a low level, as shown in the following figure;

Figure 18 COMP Underlying Configuration

```
void COMP_Init(void)
{
    COMP_Config_T    compConfig;
    /*  Configure COMP1 */
    COMP_ConfigStructInit(&compConfig);
    compConfig.invertingInput = COMP_INVERTING_INPUT_PA1;
    compConfig.output         = COMP_OUTPUT_TIM1BKIN;
    compConfig.outputPol      = COMP_OUTPUTPOL_NONINVERTED;
    compConfig.hysterrsis     = COMP_HYSTERRSIS_NO;
    compConfig.mode           = COMP_MODE_HIGHSPEED;
    COMP_Config(COMP_SELECT_COMP1,&compConfig);
    /* Enable COMP2 */
    COMP_Enable(COMP_SELECT_COMP1);
}
```

3.4 Settings of Key Parameters

All parameters in this system are configured in parameter.h of the user layer, mainly including system parameters, related parameters of backplane, related parameters of state machine, and related parameters of motor, as follows:

3.4.1 System Parameters

Table 3 System Parameters

Parameter name	Parameter description	Set value
SYS_REFV	Supply voltage of the system	3.3 (V)
SYSCLK_HSE_72MHz	Main frequency of the system	72000000 (Hz)
PWMFREQ	PWM frequency	8000 (Hz)
DEAD_TIME	PWM dead band time	1.0 (μs)
SLOWLOOP_FREQ	Control frequency of slow loop	1000 (Hz)

3.4.2 Backplane Hardware Parameters

Table 4 Parameters of Backplane Hardware

Parameter name	Parameter description	Set value
ADC_REFV	ADC reference voltage	3.3 (V)
R_SHUNT	Sampling resistance value	0.02 (Ω)
CURRENT_OPA_GAIN	Amplification factor of operational amplifier	5.0
I_MAX	Current standardization reference value	16.5 (A)
UDC_MAX	Voltage standardization reference value	69.0 (V)
U_MAX	Phase voltage standardization reference value	39.83 (V)

3.4.3 Parameters of State Machine

Table 5 Parameters of State Machine

Parameter name	Parameter description	Set value
STOP_TO_RUN_SPEED	Threshold for speed command of jumping from Stop to Run state	500 (rpm)
STARTUP_TO_SPIN_SPEED	Threshold for actual speed of jumping from Startup to Spin state	400 (rpm)
FREEWHEEL_SPEED	Stop after the speed command is below the threshold	400 (rpm)
IQ_ALIGN	IQ command value in Align state	1.0 (A)
MAXSTARTUP_SPEED	Maximum speed of open-loop rotation	500 (rpm)
STARTUP_SPEED_RAMP	Slope value of speed command under open loop	500 (rpm/s)
STARTUP_TIME	Open-loop time	1.0 (s)

3.4.4 Motor Related Parameters

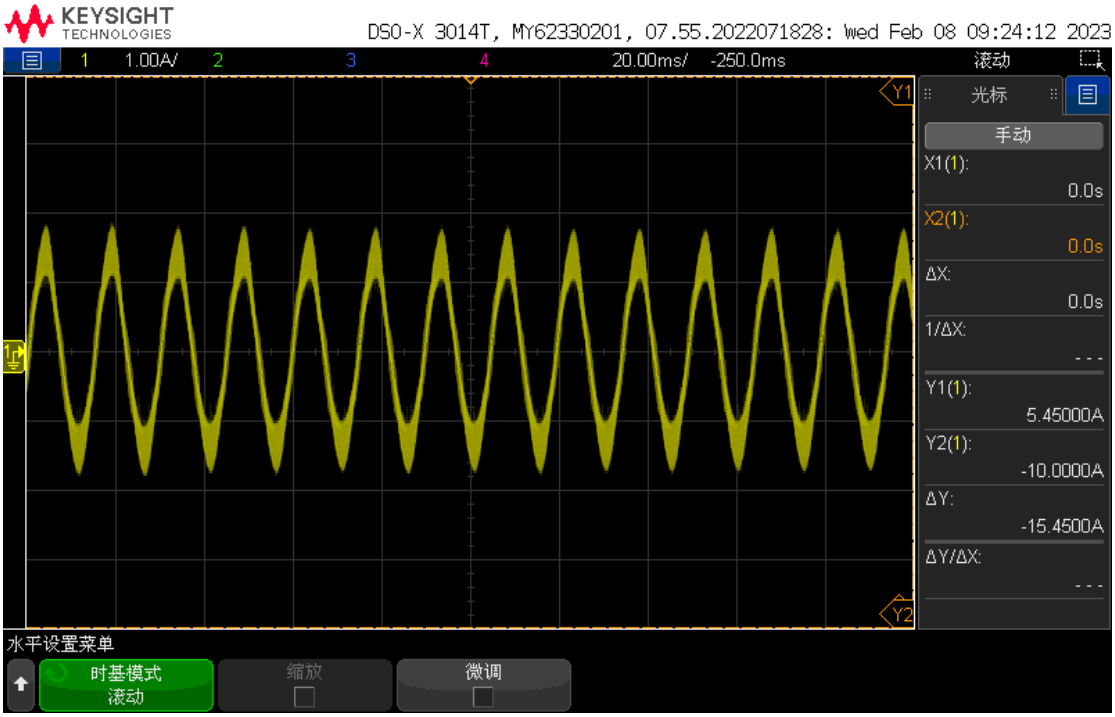
Table 6 Motor Related Parameters

Parameter name	Parameter description	Set value
Rs	Phase resistance of motor	0.15 (ohm)
Ls	Phase inductance of motor	0.00037 (H)
POLEPAIRS	Number of motor pole-pairs	2 (unit)
SPEED_MAX	Speed calibration value	5000 (rpm)

Parameter name	Parameter description	Set value
MAX_DUTY	Maximum duty cycle	0.92 (unit)
M1_IQ_KP_Q15	Q-axis current loop KP parameter Q15 format	980
M1_IQ_KI_Q15	Q-axis current loop KI parameter Q15 format	220
M1_ID_KP_Q15	D-axis current loop KP parameter Q15 format	980
M1_ID_KI_Q15	D-axis current loop KI parameter Q15 format	220
M1_SPEED_KP_Q15	Speed loop KP parameter Q15 format	16384
M1_SPEED_KI_Q15	Speed loop KI parameter Q15 format	163

4 Actual test waveform

Figure 19 Actual Test Waveform



5 Revision History

Table 7 Document Revision History

Date	Revision	Revision History
July 26, 2023	1.0	New
August 14, 2023	1.1	(1) Modified the production information form (2) Modified the format

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8. Scope of Application

The information in this document replaces the information provided in all previous versions of the document.