

# Datasheet

## Three-phase Motor Control MCU FU6815\_65\_64

Fortior Technology (Shenzhen) Co., Ltd

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## Explanation of Symbols

- The symbol “[ ]” following a register indicates a bit in the register. For example, ABCD[XY] indicates the XY bit in ABCD register.
- The symbol “x” in a register name indicates similar registers. For example, TIMx\_CR0 indicates TIM3\_CR0 and TIM4\_CR0.
- [m:n] indicates a range of bits. For example, [3:0] means the bits from bit3 to bit0.
- Pm.n indicates the n<sup>th</sup> port of the Portm. P0.0 indicates the 0<sup>th</sup> port of Port0.
- Register read and write symbols:
  - R: Read only
  - W: Write only
  - R/W: Read/write
  - W0: Only 0 can be written
  - W1: Only 1 can be written
- The symbol “-” indicates an uncertainty value or invalid value.
- The RMW instruction cannot be used for registers with different read and written representations.
- Q (number) format is to store floating-point numbers using fixed-point numbers. MSB is the sign bit, followed by integer bits and fraction bits, where lower Q bits are assigned to the fractional part and the remaining bits are assigned to the integer part. For example, for Q12, bit15 is the sign bit, bit14 ~ bit12 represent the integer part and bit11 ~ bit0 represent the fraction part. The Q12 format has a decimal range -8 ~ 7.9998 (corresponding to 0x8000 ~ 0x7FFF).

## Abbreviations

ADC	Analog to Digital Convertor
BEMF	Back Electromotive Force
BLDC	Brushless Direct Current
CRC	Cyclic Redundancy Check
DAC	Digital to Analog Convertor
DMA	Direct Memory Access
FG	Frequency Generator
FICE	Fortior Interactive Connectivity Establishment
FOC	Field Oriented Control
FOSC	Fast Oscillator
GPIO	General Purpose Input Output
I <sup>2</sup> C	Inter Integrated Circuit
IC	Integrated Circuit
IRAM	Internal RAM
IDE	Integrated Development Environment
LDO	Low Dropout Regulator
LPF	Low Pass Filter
LVD	Low Voltage Detection
MDU	Multiplication Division Unit
ME	Motor Engine
MSB	Most Significant Bit
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NC	Not Connected
PFC	Power Factor Correction
PGA	Programmable Gain Amplifier
PI/PID	Proportional Integral/Proportional Integral Derivative
PLL	Phase Locked Loop
PWM	Pulse Width Modulation
QEP	Quadrature Encoder Pulse
RAM	Random Access Memory
RMW	Read Modified Write
ROM	Read Only Memory
RSD	Rotating State Detection

RTC	Real Time Clock
SCL	Serial Clock Line
SDA	Serial Data Line
SFR	Special Function Register
SMO	Sliding Mode Observer
SOSC	Slow Oscillator
SPI	Serial Peripheral Interface
SVPWM	Space Vector PWM
TSD	Temperature Sensor Detect
UART	Universal Asynchronous Receiver/Transmitter
WDT	Watch Dog Timer
XRAM	External RAM
XSFR	External SFR

## 1 System Introduction

### 1.1 Features

- Power supply of FU6815L/FU6865Q:
  - High-voltage single-power supply mode: When VCC\_MODE = 0, external power supply 5V~28V is connected to VCC pin, and internal LDO supplies VDD5 voltage.
  - Low-voltage single-power supply mode: When VCC\_MODE = 1, external power supply 3V~5.5V is connected to VDD5 pin, and VDD5 pin is shorted to VCC pin.
  - Dual-power supply mode: When VCC\_MODE = 1, external power supply 1 (5V~36V) is connected to VCC pin, and external power supply 2 (5V) is connected to VDD5 pin.

Note: VDRV voltage of FU6865Q is supplied by external power supply.

- Power supply of FU6864Q/FU6864L:
  - Single-power supply mode: When VCC\_MODE = 0, external power supply 12V~20V is connected to VCC pin, and internal LDO supplies VDD5 voltage.
- Dual core: 8051 core and ME core
- An instruction cycle mostly takes 1 or 2 system clock cycle(s)
- 32kB Flash ROM with CRC, self-program and code protection
- 256 bytes IRAM and 3.75k bytes XRAM
- ME: Core integrating PID module, FOC module, MDU auxiliary computing module and LPF module
- 16 interrupt sources with 4 configurable priority levels
- Number of GPIOs:
  - FU6815L: 38
  - FU6865Q: 36
  - FU6864Q: 22
  - FU6864L: 24
- Timers:
  - Timer1: Timer supporting square-wave drive timing control, automatic commutation, cycle-by-cycle current limiting and Hall/BEMF-based position sensing
  - Timer2: Timer supporting PWM output, measurement of duty cycle and period of input PWM wave, measurement of the time of set PWM wave numbers, QEP decoding (FU6815L/FU6865Q), tailwind/headwind detection (FU6815L/FU6865Q), and rotation direction and speed detection of step motor
  - Timer3/Timer4: Timers supporting PWM output, and measurement of duty cycle and period of input PWM wave Timer4 supports FG generation and Timer3 supports up to 48MHz input
  - Systick Timer

- RTC
- Communication interfaces:
  - 1\*SPI (FU6815L/FU6865Q)
  - 1\*I<sup>2</sup>C
  - 2\*UARTs, supporting single-wire mode (FU6815L/FU6865Q)
  - 1\*UART, supporting single-wire mode (FU6864Q/FU6864L)
  - Dual-channel DMA: supporting data transmission via I<sup>2</sup>C/SPI/UART (FU6815L/FU6865Q)
  - Dual-channel DMA: supporting data transmission via I<sup>2</sup>C/UART (FU6864Q/FU6864L)
- Analog peripherals:
  - 12-bit ADC, operating with 1μs conversion time and internal VREF or external VREF selectable as reference voltage
  - Number of ADC channels:
    - ◆ 14 (FU6815L/FU6865Q)
    - ◆ 12 (FU6864Q)
    - ◆ 13 (FU6864L. Among them, AD0 is the internal channel.)
  - Internal VREF. 3V, 4V, 4.5V and VDD5 can be selected as the internal reference.
  - Internal VHALF, with VREF/2, 1/4 VREF, 1/8 VREF or 25/64 VREF as the internal reference
  - Four standalone operational amplifier(s), where PGA is configurable
  - Four-channel analog comparator
  - DAC: Single-channel 9-bit, single-channel 8-bit, single-channel 6-bit
- Driver Type
  - PWM output (FU6815L)
  - Built-in MOSFET driver: 6N pre-driver output (FU6865Q/FU6864Q/FU6864L)
- FOC module supports single/dual/triple-shunt current sampling
- PFC
- System clock
  - Built-in 24MHz high-speed RC oscillator
  - Built-in 32.8kHz low-speed RC oscillator
  - External 32768Hz crystal clock (FU6815L/FU6865Q)
- WDT
- LVD
- TSD
- Two-wire FICE protocol based in-circuit emulation

## 1.2 Applications

The chip can be used for the drive of sensorless or sensed BLDC/PMSM motors, single-phase/three-phase induction motors and servo motors.

■ Applications:

- FU6815L: Washing machines, refrigerators, range hoods, air conditioner indoor units, ceiling fans, pedestal fans, vacuum cleaners, hair dryers, industrial fans, etc.
- FU6865Q: Water pumps, compressors, fans, two-wheel/three-wheel electric vehicles, power tools, drones, vacuum cleaners, etc.
- FU6864Q: Refrigerators, range hoods, air conditioner indoor units, ceiling fans, pedestal fans, vacuum cleaners, hair dryers, industrial fans, etc.
- FU6864L: Refrigerators, range hoods, air conditioner indoor units, ceiling fans, pedestal fans, vacuum cleaners, hair dryers, industrial fans, etc.

## 1.3 Overview

The high-performance motor drive chip incorporates ME core and 8051 core. ME core integrates FOC, MDU, LPF, PID and SVPWM modules that allow for automatic calculation of FOC or square-wave control by the hardware for sensed/sensorless BLDC/PMSM motors. 8051 core is used for parameter configuration and routine processing. Most of 8051 core instruction cycle takes 1T or 2T clock cycle(s). The dual cores work in parallel to achieve high-performance motor control. The chip integrates high-speed operational amplifiers, comparators, PWM (FU6815L), pre-driver (FU6865Q/FU6864Q/FU6864L), high-speed ADC, CRC, SPI, I<sup>2</sup>C, UART, Timers, built-in high-voltage LDO, which are suitable for FOC or square-wave based BLDC/PMSM motors.

The above are the general descriptions on the product family. The features vary by models. For details, see sections 2 Pin Definitions and 4 Ordering Information.

For concise description and easy differentiation, if it is specified that a feature is applied to a specific model, the feature is exclusive to this model. For example, FU6864 refers to all models of FU6864. Otherwise, the feature is a common feature of the product family.

FU6815 includes FU6815L(LQFP48)

FU6865 includes FU6865Q(QFN56)

FU6864 includes FU6864Q(QFN48-38) and FU6864L(LQFP52)



## 1.4 Functional Block Diagram

### 1.4.1 FU6815L

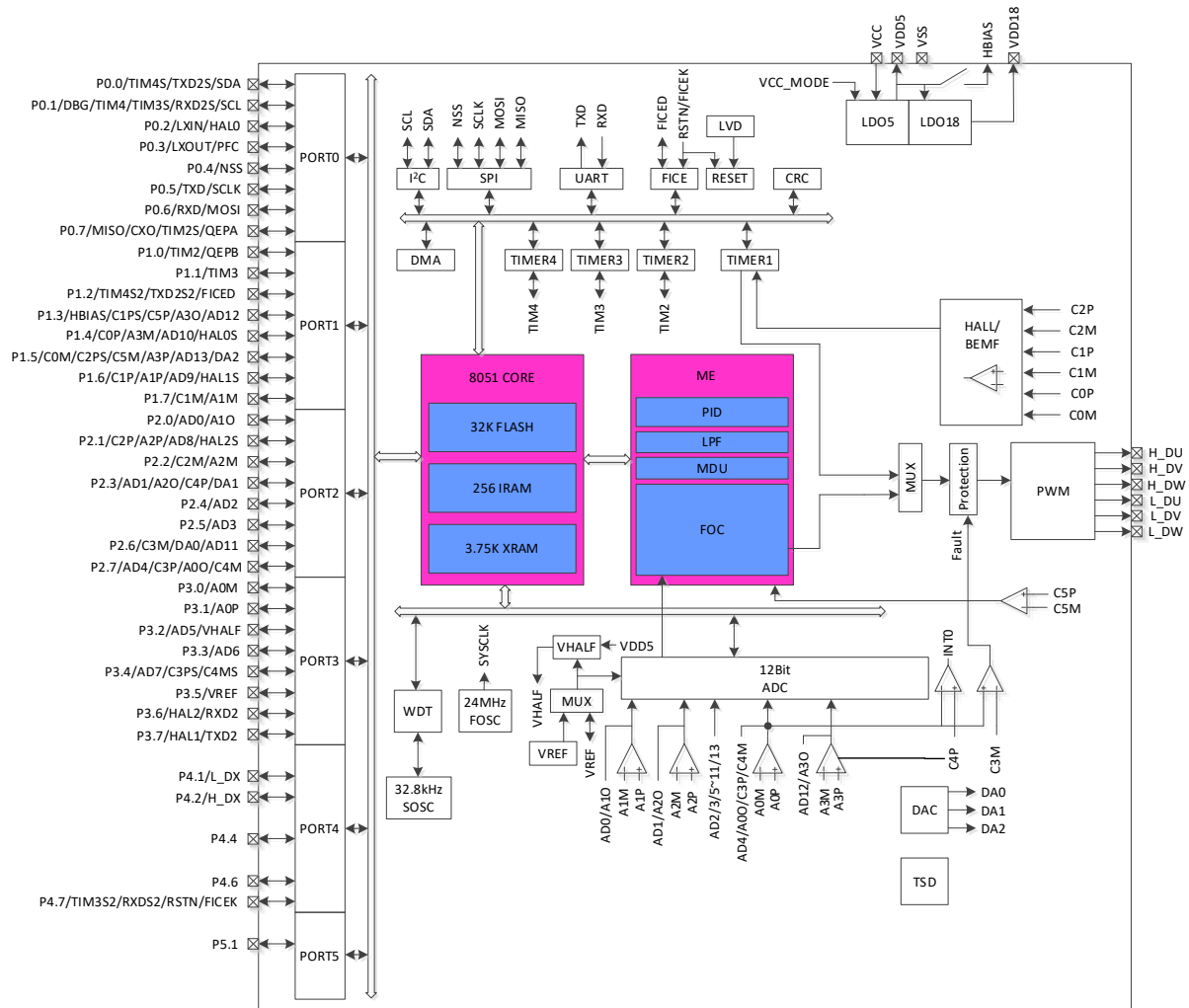


Figure 1-1 Functional Block Diagram of FU6815L11

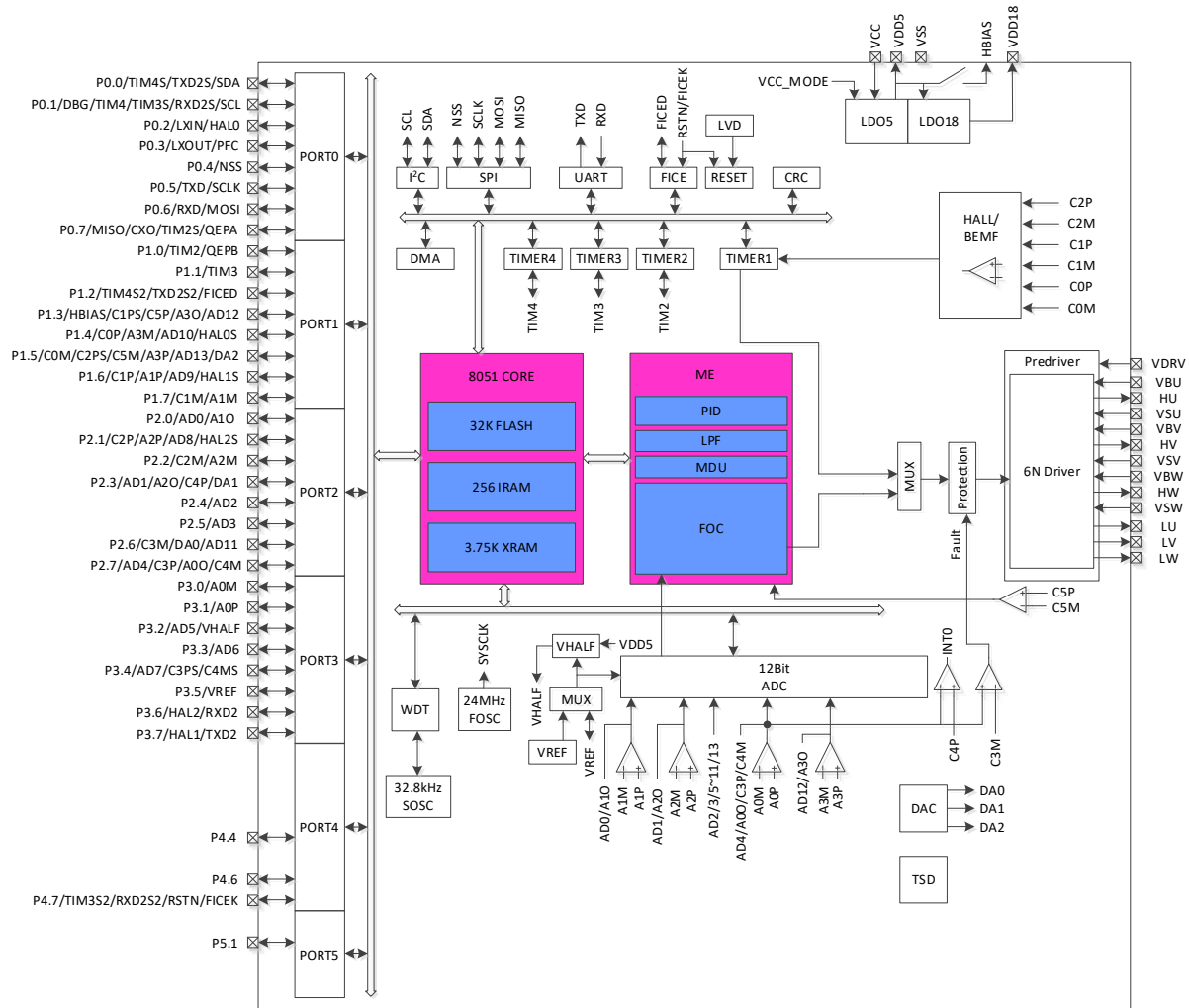
**1.4.2 FU6865Q**


Figure 1-2 Functional Block Diagram of FU6865Q

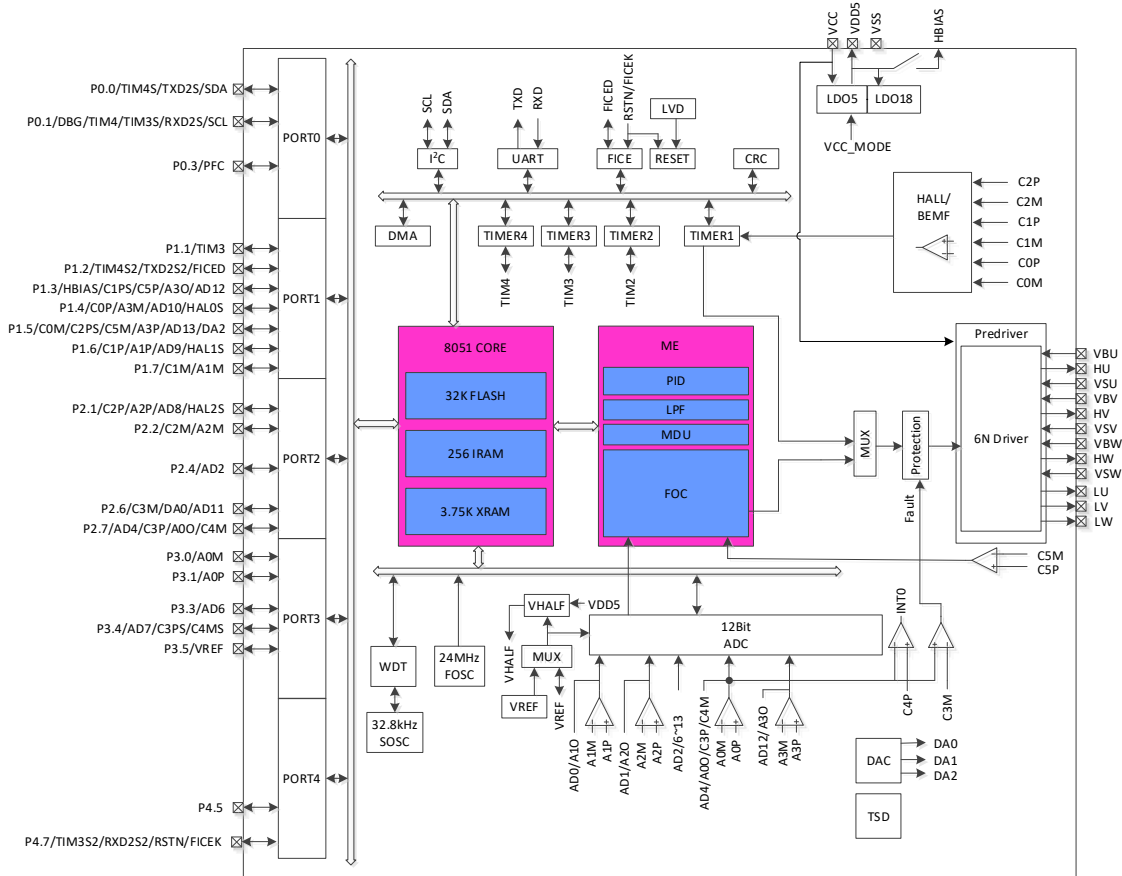
**1.4.3 FU6864Q**


Figure 1-3 Functional Block Diagram of FU6864Q

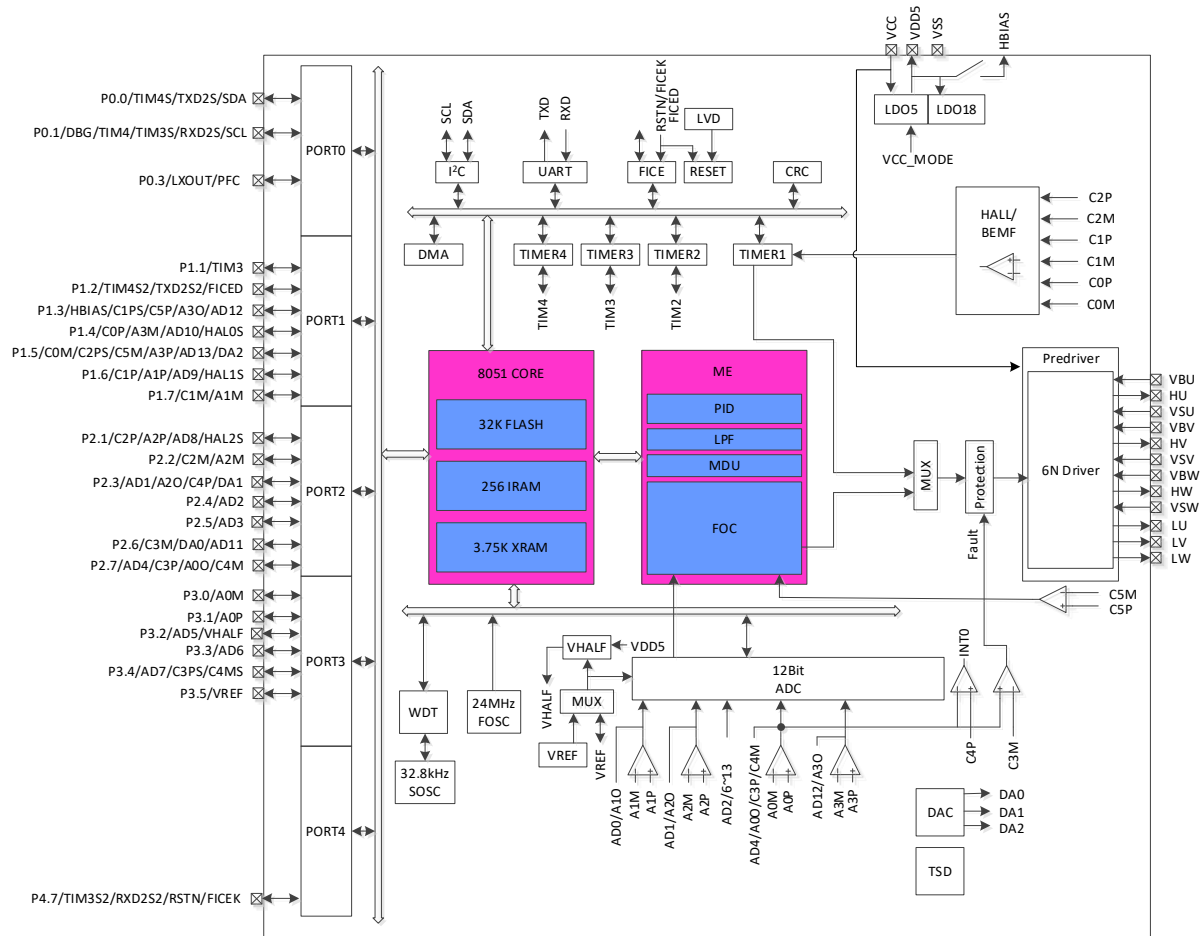
**1.4.4 FU6864L**


Figure 1-4 Functional Block Diagram of FU6864L

## 1.5 Memory Organization

The internal storage space is divided into Program Memory and Data Memory, which are independently addressed.

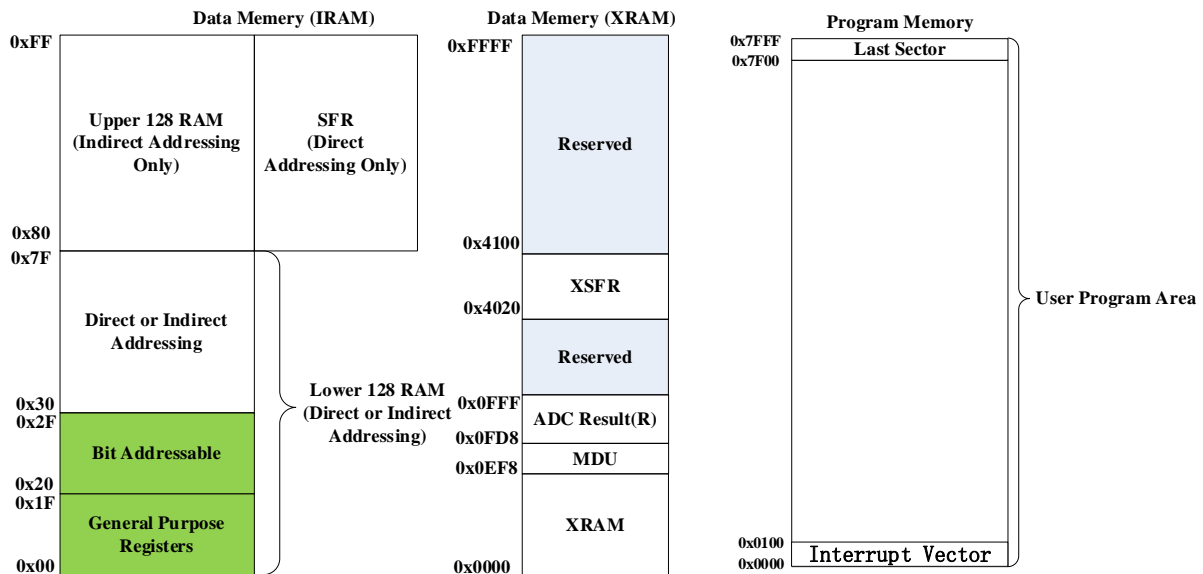


Figure 1-5 Memory Organization

### 1.5.1 Program Memory

The chip implements this program memory as Flash memory with a block from addresses 0x0000 to 0x7FFF to store control programs to store control programs.

The first sector (0x0000~0x00FF) is the interrupt vector address area, which is used to store the start address of each interrupt routine. The last sector (0x7F00~0x7FFF) contains internal control bits of the chip.

### 1.5.2 Data Memory

The data memory is divided into External Data Memory and Internal Data Memory, as shown in Figure 1-5.

The External Data Memory is addressed from 0x0000 to 0xFFFF, which can be accessed only with MOVX instructions. It comprises XRAM (0x0000~0x0EF7), extended control register space (0x4020~0x40FF), MDU register space (0x0EF8~0x0FD7) and ADC result memory area (0x0FD8~0x0FFF).

The Internal Data Memory is addressed from 0x00 to 0xFF. Locations 0x00 ~ 0x1F are addressable as 4 banks of general purpose registers, each bank consisting of 8 registers, adding up to 32 registers. Locations 0x20 ~ 0x7F are used for general purpose RAM memory, supporting direct and indirect addressing. Locations (0x20 ~ 0x2F) are 16-bit addressable. When locations 0x80 ~ 0xFF are accessed by indirect addressing, it points to RAM. When locations 0x80 ~ 0xFF are accessed by direct addressing, it points to SFR.

**1.5.3 SFR**

Table 1-1 SFR Address Mapping

Addr	0(8)	1(9)	2(A)	3(B)	4(C)	5(D)	6(E)	7(F)
0xF8	DRV_OUT	PI_CR		P5_OE	P0_OE	P1_OE	P2_OE	P3_OE
0xF0	B							
0xE8		P4_OE						
0xE0	ACC	CMP_CR4	HALL_CR					
0xD8	UT2_CR	EVT_FILT	CMP_CR2	LVSR	CMP_CR3			
0xD0	PSW	P1_IE	P1_IF	P4_IE	P4_IF	CMP_CR0	CMP_CR1	CMP_SR
0xC8		RST_SR						
0xC0	P5	MDU_CR						
0xB8	P4							
0xB0	P3							
0xA8	IE	TIM2_CR1	TIM2_CNTRL	TIM2_CNTRH	TIM2_DRL	TIM2_DRH	TIM2_ARRL	TIM2_ARRH
0xA0	P2	TIM2_CR0	TIM3_CNTRL	TIM3_CNTRH	TIM3_DRL	TIM3_DRH	TIM3_ARRL	TIM3_ARRH
0x98	UT_CR	UT_DR	UT_BAUDL	UT_BAUDH	TIM3_CR0	TIM3_CR1	TIM4_CR0	TIM4_CR1
0x90	P1		TIM4_CNTRL	TIM4_CNTRH	TIM4_DRL	TIM4_DRH	TIM4_ARRL	TIM4_ARRH
0x88	TCON	UT2_DR	IP0	IP1	IP2	IP3		
0x80	P0	SP	DPL	DPH	FLA_KEY	FLA_CR		PCON

## Notes:

- Registers containing the symbol “\_\_” are 16-bit snapshot registers. Snapshot registers are the dynamic registers which shall be read using variables. The value will be incorrect when the register is read directly.
- 8-bit MCU shall read a 16-bit register twice to get the value, the 8 high-order bits and the 8 low-order bits respectively. The result will be incorrect when 8 low-order bits of the register change after MCU has read the 8 high-order bits. Therefore, when 8 high-order bits of the snapshot register are read by MCU, the corresponding 8 low-order bits are stored and read.
- Snapshot register must be read as a whole, the 8 high-order bits first and then the 8 low-order bits.

**1.5.4 XSFR**
**Table 1-2 XSFR Address Mapping**

Addr	0(8)	1(9)	2(A)	3(B)	4(C)	5(D)	6(E)	7(F)
0x40F8	IAC_KPH	IAC_KPL	IAC_KIH	IAC_KIL	IAC_UKMAXH	IAC_UKMAXL	IAC_UKMINH PFC_OUTARRH PFC_TRGDLY	IAC_UKMINL PFC_OUTARRL
0x40F0	UDC_UKMAXH	UDC_UKMAXL	UDC_UKMINH PFC_CR1	UDC_UKMINL PFC_KM	IAC_REFH	IAC_REFL	IAC_UKH	IAC_UKL
0x40E8	UDC_REFH	UDC_REFL	UDC_UKH	UDC_UKL	UDC_KPH	UDC_KPL	UDC_KIH	UDC_KIL
0x40E0	PFC_CR0	PFC_ADCCH	PFC_CSOH	PFC_CSOL	PFC_ARRH PFC_UAVGH	PFC_ARRL PFC_UAVGL	PFC_DRH	PFC_DRL
0x40D8	FOC_POWH FOC_EOMEKLPF	FOC_POWL	FOC_IAMAXH	FOC_IAMAXL	FOC_IBMAXH	FOC_IBMAXL	FOC_ICMAXH	FOC_ICMAXL
0x40D0	FOC_EALPH	FOC_EALPL	FOC_EBETH	FOC_EBETL	FOC_EOMEH	FOC_EOMEL	FOC_UQEXH FOC_KFGH	FOC_UQEXL FOC_KFGL
0x40C8	FOC_IBH FOC_LQH	FOC_IBL FOC_LQL	FOC_IAH FOC_LDH	FOC_IAL FOC_LDL	FOC_THETAH	FOC_THETAL	FOC_ETHETAH	FOC_ETHETAL
0x40C0	FOC_IBETH FOC_IQ_LPFK	FOC_IBETL FOC_ID_LPFK	FOC_VBETH FOC_UDCPSH	FOC_VBETL FOC_UDCPSL	FOC_VALPH FOC_UQCPH	FOC_VALPL FOC_UQCPSL	FOC_ICH FOC_FLUXH	FOC_ICL FOC_FLUXL
0x40B8	FOC_UDH	FOC_UDL	FOC_UQH	FOC_UQL	FOC_IDH	FOC_IDL	FOC_IQH	FOC_IQL
0x40B0	FOC_DMAXH FOC_OMEESTH	FOC_DMAXL FOC_OMEESTL	FOC_DMINH FOC_ATAN_THETAH	FOC_DMINL FOC_ATAN_THETAL	FOC_QMAXH	FOC_QMAXL	FOC_QMINH	FOC_QMINL
0x40A8	FOC_RTHESTEPH	FOC_RTHESTEPL	FOC_RTHEACCH FOC_EOMELPFH	FOC_RTHEACCL FOC_EOMELPFL	FOC_RTHECNT	FOC_THECOR CMP_SAMR	FOC_THECOMP FOC_EMFH	FOC_THECOMPL FOC_EMFL
0x40A0	FOC_CR1	FOC_CR2	FOC_TSMIN	FOC_TGLI	FOC_TBLO	FOC_TRGDLY	FOC_CSOH	FOC_CSOL
0x4098	FOC_UDCFLTH TIM1_ITRIPH	FOC_UDCFLTL TIM1_ITRIPL	PFC_UACH	PFC_UACL	PFC_IACH	PFC_IACL	FOC_CR3	FOC_CR0
0x4090	FOC_IDREFH TIM1_URESH	FOC_IDREFL TIM1_URESL	FOC_IQREFH TIM1_KRMAS	FOC_IQREFL TIM1_KFMIN	FOC_QKPH TIM1_KFH	FOC_QKPL TIM1_KFL	FOC_QKIH TIM1_KRH	FOC_QKIL TIM1_KRL
0x4088	FOC_EK3H TIM1_RARRH	FOC_EK3L TIM1_RARRL	FOC_EK4H TIM1_RCNTRH	FOC_EK4L TIM1_RCNTRL	FOC_EK1H TIM1_UCOPH	FOC_EK1L TIM1_UCOPL	FOC_EK2H TIM1_UFLPH	FOC_EK2L TIM1_UFLPL
0x4080	FOC_FBASEH TIM1_DBR7H	FOC_FBASEL TIM1_DBR7L	FOC_EFREQACCH TIM1_BCNTRH	FOC_EFREQACCL TIM1_BCNTRL	FOC_EFREQMINH TIM1_BCCRH	FOC_EFREQMINL TIM1_BCCRL	FOC_EFREQHOLDH TIM1_BARRH	FOC_EFREQHOLDL TIM1_BARRL
0x4078	FOC_KSLIDEH TIM1_DBR3H	FOC_KSLIDEL TIM1_DBR3L	FOC_EKLPFMINH TIM1_DBR4H	FOC_EKLPFMINL TIM1_DBR4L	FOC_DKIH TIM1_DBR5H	FOC_DKIL TIM1_DBR5L	FOC_OMEKLPFH TIM1_DBR6H	FOC_OMEKLPFL TIM1_DBR6L
0x4070	TIM1_BCORH FOC_DKPH	TIM1_BCORL FOC_DKPL	TIM1_CR5		FOC_EKPH TIM1_DBR1H	FOC_EKPL TIM1_DBR1L	FOC_EKIH TIM1_DBR2H	FOC_EKIL TIM1_DBR2L
0x4068	TIM1_CR0	TIM1_CR1	TIM1_CR2	TIM1_CR3	TIM1_CR4	TIM1_IER	TIM1_SR	FOC_EFREQMAX
0x4060	DRV_DTR	DRV_SR	DRV_CR	PFC_CR2	SYST_ARRH	SYST_ARRL	DRV_CNTRH	DRV_CNTRL
0x4058	DRV_DRH	DRV_DRL	DRV_COMRH	DRV_COMRL	DRV_CMRH	DRV_CMRL	DRV_ARRH	DRV_ARRL
0x4050	P1_AN	P2_AN	P3_AN	P0_PU	P1_PU	P2_PU	P3_PU	P4_PU
0x4048	P5_PU	DAC2_DR	DAC1_DR	DAC0_DR	PH_SEL	PH_SEL1	AMP_CR0	VREF_VHALF_CR
0x4040	DMA1_BAH	DMA1_BAL	UT2_BAUDH	UT2_BAUDL	CAL_CR0	CAL_CR1	AMP_CR2	
0x4038	ADC_SCYC	ADC_CR	DMA0_CR0	DMA1_CR0	DMA0_LEN	DMA1_LEN	DMA0_BAH	DMA1_BAL
0x4030	SPI_CR0	SPI_CR1	SPI_CLK	SPI_DR	AMP_CR1	DAC_CR	ADC_MASKH	ADC_MASKL
0x4028	I2C_CR	I2C_ID	I2C_DR	I2C_SR	RTC_TMH	RTC_TML	RTC_STA	TSD_CR

Addr	0(8)	1(9)	2(A)	3(B)	4(C)	5(D)	6(E)	7(F)
0x4020		CRC_DIN	CRC_CR	CRC_DR	CRC_BEG	CRC_CNT	WDT_CR	WDT_ARR
0x0FF0	AD12_DRH	AD12_DRL	AD13_DRH	AD13_DRL				
0x0FE8	AD8_DRH	AD8_DRL	AD9_DRH	AD9_DRL	AD10_DRH	AD10_DRL	AD11_DRH	AD11_DRL
0x0FE0	AD4_DRH	AD4_DRL	AD5_DRH	AD5_DRL	AD6_DRH	AD6_DRL	AD7_DRH	AD7_DRL
0x0FD8	AD0_DRH	AD0_DRL	AD1_DRH	AD1_DRL	AD2_DRH	AD2_DRL	AD3_DRH	AD3_DRL
0x0FD0		LPF0_K		LPF0_X		LPF0_YH		LPF0_YL
0x0FC8		LPF1_K		LPF1_X		LPF1_YH		LPF1_YL
0x0FC0		PI0_UKH		PI0_UKL		PI0_UKMAX		PI0_UKMIN
0x0FB8		PI0_KP		PI0_EK1		PI0_EK		PI0_KI
0x0FB0		PI1_UKH		PI1_UKL		PI1_UKMAX		PI1_UKMIN
0x0FA8		PI1_KP		PI1_EK1		PI1_EK		PI1_KI
0x0FA0		MUL0_MA		MUL0_MB		MUL0_MCH		MUL0_MCL
0x0F98		MUL1_MA		MUL1_MB		MUL1_MCH		MUL1_MCL
0x0F90		DIV0_DB		DIV0_DQH		DIV0_DQL		DIV0_DR
0x0F88		DIV1_DQL		DIV1_DR		DIV0_DAH		DIV0_DAL
0x0F80		DIV1_DAH		DIV1_DAL		DIV1_DB		DIV1_DQH
0x0F78		LPF2_K		LPF2_X		LPF2_YH		LPF2_YL
0x0F70		LPF3_K		LPF3_X		LPF3_YH		LPF3_YL
0x0F68		PI2_UKMAX		PI2_UKMIN		PI2_KD		PI2_EK2
0x0F60		PI2_EK		PI2_KI		PI2_UKH		PI2_UKL
0x0F58		PI3_KD		PI3_EK2		PI2_KP		PI2_EK1
0x0F50		PI3_UKH		PI3_UKL		PI3_UKMAX		PI3_UKMIN
0x0F48		PI3_KP		PI3_EK1		PI3_EK		PI3_KI
0x0F40		MUL2_MA		MUL2_MB		MUL2_MCH		MUL2_MCL
0x0F38		MUL3_MA		MUL3_MB		MUL3_MCH		MUL3_MCL
0x0F30		DIV2_DB		DIV2_DQH		DIV2_DQL		DIV2_DR
0x0F28		DIV3_DQL		DIV3_DR		DIV2_DAH		DIV2_DAL
0x0F20		DIV3_DAH		DIV3_DAL		DIV3_DB		DIV3_DQH
0x0F18		SCAT0_SIN		SCAT0_THE		SCAT0_RES1		SCAT0_RES2
0x0F10		SCAT1_THE		SCAT1_RES1		SCAT1_RES2		SCAT0_COS
0x0F08		SCAT2_RES1		SCAT2_RES2		SCAT1_COS		SCAT1_SIN
0x0F00		SCAT3_RES2		SCAT2_COS		SCAT2_SIN		SCAT2_THE
0x0EF8		SCAT3_COS		SCAT3_SIN		SCAT3_THE		SCAT3_RES1

**Notes:**

- Registers containing the symbol “\_” are 16-bit snapshot registers. Snapshot registers are the dynamic registers which shall be read using variables. The value will be incorrect when the register is read directly.
- 8-bit MCU shall read a 16-bit register twice to get the value, the 8 high-order bits and the 8 low-order bits respectively. The result will be incorrect when 8 low-order bits of the register change after MCU has read the 8 high-order bits. Therefore, when 8 high-order bits of the snapshot register are read by MCU, the corresponding 8 low-order bits are stored and read.
- Snapshot register must be read as a whole, the 8 high-order bits first and then the 8 low-order bits.



## 2 Pin Definitions

The IO types are defined as follows:

- DI = Digital Input
- DO = Digital Output
- DB = Digital Bidirectional
- AI = Analog Input
- AO = Analog Output
- AB = Analog Bidirectional
- P = Power Supply

### 2.1 FU6815L LQFP48 Pins

Table 2-1 FU6815L LQFP48 Pin Descriptions

Pin	FU6815L LQFP48	IO Type	Function Description
P2.2/ C2M/ A2M	1	DB/ AI/ AI	GPIO CMP2 negative input AMP2 negative input
P2.3/ AD1/ A2O/ C4P/ DA1	2	DB/ AI/ AO/ AI/ DO	GPIO Input of ADC channel 1 AMP2 output CMP4 positive input DAC1 output, without Buffer output
P2.4/ AD2	3	DB/ AI	GPIO Input of ADC channel 2 for bus voltage sampling
P2.5/ AD3	4	DB/ AI	GPIO Input of ADC channel 3
P2.6/ C3M/ DA0/ AD11	5	DB/ AI/ AO/ AI	GPIO CMP3 negative input DAC0 output, without Buffer output Input of ADC channel 11
P2.7/ AD4/ C3P/ A0O/ C4M	6	DB/ AI/ AI/ AO/ AI	GPIO Input of ADC channel 4 for bus current sampling CMP3 positive input AMP0 output CMP4 negative input
P3.0/ A0M	7	DB/ AI	GPIO AMP0 negative input
P3.1/ A0P	8	DB/ AI	GPIO AMP0 positive input
P3.2/ AD5/ VHALF	9	DB/ AI/ AO	GPIO Input of ADC channel 5 VREF/2 output with an external 1 $\mu$ F capacitor
P3.3/ AD6	10	DB/ AI	GPIO Input of ADC channel 6
P3.4/ AD7/ C3PS/ C4MS	11	DB/ AI/ AI/ AI	GPIO Input of ADC channel 7 CMP3 positive input after function switching CMP4 negative input after function switching

Pin	FU6815L LQFP48	IO Type	Function Description
P3.5/ VREF	12	DB/ AB	GPIO ADC external VREF input or internal VREF output, with an external 1 $\mu$ F ~ 4.7 $\mu$ F capacitor
P4.4	13	DB	GPIO, configurable as INT1 input
P5.1	14	DB	GPIO
P3.6/ HAL2/ RXD2	15	DB/ DI/ DB	GPIO Hall-IC2 logic level input UART2 RXD input in two-wire mode or TXD output/RXD input in single-wire mode
P3.7/ HAL1/ TXD2	16	DB/ DI/ DO	GPIO Hall-IC1 logic level input UART2 TXD output
P0.0/ TIM4S/ TXD2S/ SDA	17	DB/ DB/ DB/ DO	GPIO, configurable as INT0 input Timer4 input/output after function switching UART2 TXD output after function switching I <sup>2</sup> C SDA, configured as collector open-drain output
P0.1/ DBG/ TIM4/ TIM3S/ RXD2S/  SCL	18	DB/ DO/ DB/ DB/ DB/ DB	GPIO, configurable as INT0 input Debug port Timer4 input/output Timer3 input/output after function switching UART2 RXD input in two-wire mode or TXD output/RXD input in single-wire mode after function switching I <sup>2</sup> C SCL, configured as collector open-drain output
P0.2/ LXIN/ HAL0	19	DB/ AI/ DI	GPIO, configurable as INT0 input 32768Hz crystal clock input Hall-IC0 logic level input
P0.3/ LXOUT/ PFC	20	DB/ AO/ DO	GPIO, configurable as INT0 input 32768Hz crystal clock input PFCPWM output
P0.4/ NSS	21	DB/ DB	GPIO, configurable as INT1 input SPI NSS
P0.5/ TXD/ SCLK	22	DB/ DO/ DB	GPIO, configurable as INT0 input UART1 TXD output SPI SCLK
P0.6/ RXD/  MOSI	23	DB/ DB/ DB	GPIO, configurable as INT0 input UART1 RXD input in two-wire mode or TXD output/RXD input in single-wire mode SPI MOSI, master output or slave input
P0.7/ MISO/ CXO/ TIM2S/ QEPA	24	DB/ DB/ DO/ DB/ DI	GPIO SPI MISO, master input or slave output Test port for comparator output Timer2 input/output after function switching QEP encode A input
P1.0/ TIM2/ QEPB	25	DB/ DB/ DI	GPIO, configurable as INT1 input Timer2 input/output QEP encode B input
P1.1/ TIM3	26	DB/ DB	GPIO, configurable as INT0/INT1 input Timer3 input/output
P4.1/ L_DX	27	DB/ DO	GPIO, configurable as INT1 input Low-side X-phase PWM output
P4.2/ H_DX	28	DB/ DO	GPIO, configurable as INT1 input High-side X-phase PWM output
L_DU	29	DO	Low-side U-phase PWM output
L_DV	30	DO	Low-side V-phase PWM output
L_DW	31	DO	Low-side W-phase PWM output
H_DU	32	DO	High-side U-phase PWM output
H_DV	33	DO	High-side V-phase PWM output

Pin	FU6815L LQFP48	IO Type	Function Description
H_DW	34	DO	High-side W-phase PWM output
VCC	35	P	Power input. The voltage range is determined by VCC_MODE, with an external filter capacitor of 4.7μF or larger. <ul style="list-style-type: none"> <li>■ High-voltage single-power supply mode: When VCC_MODE = 0, external power supply 5V~28V is connected to VCC pin, and internal LDO supplies VDD5 voltage.</li> <li>■ Low-voltage single-power supply mode: When VCC_MODE = 1, external power supply 3V~5.5V is connected to VDD5 pin, and VDD5 pin is shorted to VCC pin.</li> </ul>
VSS	36	P	Ground
VDD5	37	P	Mid-voltage power input or 5V LDO power output is determined by VCC_MODE. See descriptions on VCC pin for power connection. It is connected with an external capacitor of 1μF or above. Mid-voltage power input or 5V LDO power output is determined by VCC_MODE. When VCC_MODE = 0, internal LDO outputs 5V power supply. When VCC_MODE = 1, 3V~5.5V external power is supplied.
P4.6	38	DB	GPIO, configurable as INT1 input
P4.7/ TIM3S2/ RXD2S2/  RSTN/ FICEK	39	DI/ DI/ DB/  DI/ DI	GPIO, used as an input only and configured with pull-up or pull-down resistor Timer3 input after function switching UART2 RXD input in two-wire mode or TXD output/RXD input in single-wire mode after function switching Input of external reset; Built-in pull-up resistor FICE SCL
VDD18	40	P	1.8V LDO output with an external 1μF ~ 4.7μF capacitor
P1.2/ TIM4S2/ TXD2S2/ FICED	41	DB/ DB/ DO/ DB	GPIO, configurable as INT1 input Timer4 input/output after function switching UART2 TXD output after function switching FICE SDA
P1.3/ HBIAS/  C1PS/ C5P/ A3O/ AD12	42	DB/ DO/  AI/ AI/ DO/ AI	GPIO, configurable as INT1 input Hall bias power supply, internally connected to VDD5 via a switch to output large current CMP1 positive input after function switching CMP5 positive input AMP3 output Input of ADC channel 12
P1.4/ C0P/ A3M/ AD10/ HAL0S	43	DB/ AI/ AI/ AI/ DI	GPIO, configurable as INT1 input CMP0 positive input AMP3 negative input Input of ADC channel 10 Hall-IC0 logic level input after function switching
P1.5/ C0M/ C2PS/ C5M/ A3P/ AD13/ DA2	44	DB/ AI/ AI/ AI/ AI/ AI/ AO	GPIO, configurable as INT1 input CMP0 negative input CMP2 positive input after function switching CMP5 negative input AMP3 positive input Input of ADC channel 13 DAC2 output, without buffer output
P1.6/ C1P/ A1P/ AD9/ HAL1S	45	DB/ AI/ AI/ AI/ DI	GPIO, configurable as INT1 input CMP1 positive input AMP1 positive input Input of ADC channel 9 Hall-IC1 logic level input after function switching
P1.7/ C1M/ A1M	46	DB/ AI/ AI	GPIO, configurable as INT1 input CMP1 negative input AMP1 negative input

Pin	FU6815L LQFP48	IO Type	Function Description
P2.0/ AD0/ A10	47	DB/ AI/ AO	GPIO Input of ADC channel 0 AMP1 output
P2.1/ C2P/ A2P/ AD8/ HAL2S	48	DB/ AI/ AI/ AI/ DI	GPIO CMP2 positive input AMP2 positive input Input of ADC channel 8 Hall-IC2 logic level input after function switching

## 2.2 FU6815L LQFP48 Pinout Diagram

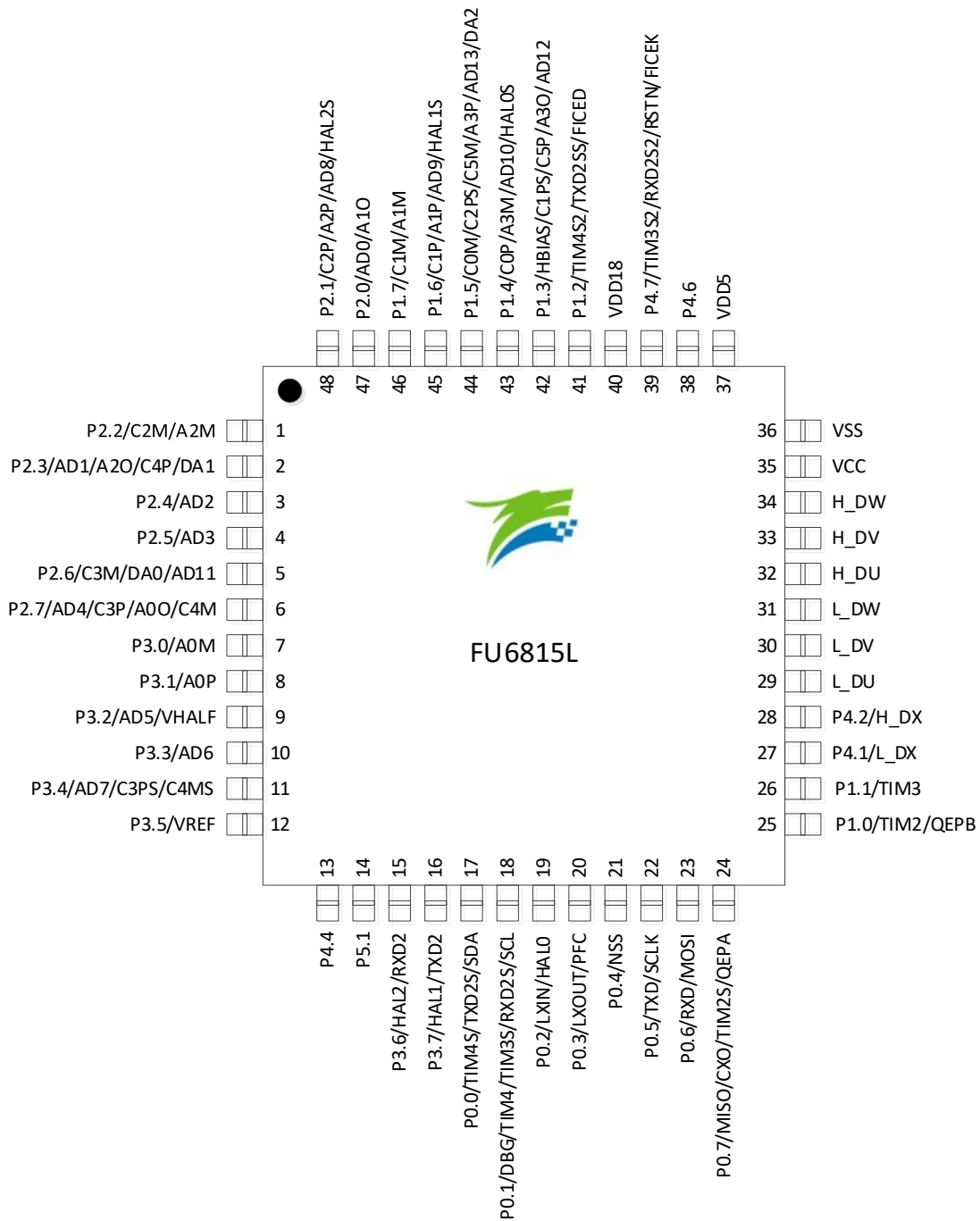


Figure 2-1 FU6815L LQFP48 Pinout Diagram

**2.3 FU6865Q QFN56 Pins**

Table 2-2 FU6865Q QFN56 Pin Descriptions

Pin	FU6865Q QFN56	IO Type	Function Description
VSU	1	P	6N pre-driver U-phase input, as GND reference for U-phase high-side bootstrap
HU	2	DO	6N pre-driver high-side U-phase PWM output
VBU	3	P	6N pre-driver high-side U-phase bootstrap power supply
VSV	4	P	6N pre-driver V-phase input, as GND reference for V-phase high-side bootstrap
HV	5	DO	6N pre-driver high-side V-phase PWM output
VBV	6	P	6N pre-driver high-side V-phase bootstrap power supply
VSW	7	P	6N pre-driver W-phase input, as GND reference for W-phase high-side bootstrap
HW	8	DO	6N pre-driver high-side W-phase PWM output
VBW	9	P	6N pre-driver high-side W-phase bootstrap power supply
VCC	10	P	Power input. The voltage range is determined by VCC_MODE, with an external filter capacitor of 4.7 $\mu$ F or larger. <ul style="list-style-type: none"> <li>■ High-voltage single-power supply mode: When VCC_MODE = 0, external power supply 5V~28V is connected to VCC pin, and internal LDO supplies VDD5 voltage.</li> <li>■ Low-voltage single-power supply mode: When VCC_MODE = 1, external power supply 3V~5.5V is connected to VDD5 pin, and VDD5 pin is shorted to VCC pin.</li> </ul>
VSS	11	P	Ground
VDD5	12	P	Internal LDO outputs 5V power supply, with an external 1 $\mu$ F or above capacitor. Power input or 5V internal LDO output, which is determined by VCC_MODE, with an external filter capacitor of 1 $\mu$ F or above. See descriptions on VCC pin for details.
P4.6	13	DB	GPIO, configurable as INT1 input
P4.7/ TIM3S2/ RXD2S2/ RSTN/ FICEK	14	DI/ DI/ DB/ DI/ DI	GPIO, used as an input only and configured with pull-up or pull-down resistor Timer3 input after function switching UART2 RXD input in two-wire mode or TXD output/RXD input in single-wire mode after function switching Input of external reset; Built-in pull-up resistor FICE SCL
VDD18	15	P	1.85V LDO output with an external 1 $\mu$ F ~ 4.7 $\mu$ F capacitor
VSS	16	P	Ground
P1.2/ TIM4S2/ TXD2S2/ FICED	17	DB/ DB/ DO/ DB	GPIO, configurable as INT1 input Timer4 input/output after function switching UART2 TXD output after function switching FICE SDA
P1.3/ HBIAS/ C1PS/ C5P/ A3O/ AD12	18	DB/ DO/ AI/ AI/ DO/ AI	GPIO, configurable as INT1 input Hall bias power supply, internally connected to VDD5 via a switch to output large current CMP1 positive input after function switching CMP5 positive input AMP3 output Input of ADC channel 12
P1.4/ C0P/ A3M/ AD10/ HAL0S	19	DB/ AI/ AI/ AI/ DI	GPIO, configurable as INT1 input CMP0 positive input AMP3 negative input Input of ADC channel 10 Hall-IC0 logic level input after function switching

Pin	FU6865Q QFN56	IO Type	Function Description
P1.5/ C0M/ C2PS/ C5M/ A3P/ AD13/ DA2	20	DB/ AI/ AI/ AI/ AI/ AI/ AO	GPIO, configurable as INT1 input CMP0 negative input CMP2 positive input after function switching CMP5 negative input AMP3 positive input Input of ADC channel 13 DAC2 output, without buffer output
P1.6/ C1P/ A1P/ AD9/ HAL1S	21	DB/ AI/ AI/ AI/ DI	GPIO, configurable as INT1 input CMP1 positive input AMP1 positive input Input of ADC channel 9 Hall-IC1 logic level input after function switching
P1.7/ C1M/ A1M	22	DB/ AI/ AI	GPIO, configurable as INT1 input CMP1 negative input AMP1 negative input
P2.0/ AD0/ A1O	23	DB/ AI/ AO	GPIO Input of ADC channel 0 AMP1 output
P2.1/ C2P/ A2P/ AD8/ HAL2S	24	DB/ AI/ AI/ AI/ DI	GPIO CMP2 positive input AMP2 positive input Input of ADC channel 8 Hall-IC2 logic level input after function switching
P2.2/ C2M/ A2M	25	DB/ AI/ AI	GPIO CMP2 negative input AMP2 negative input
P2.3/ AD1/ A2O/ C4P/ DA1	26	DB/ AI/ AO/ AI/ DO	GPIO Input of ADC channel 1 AMP2 output CMP4 positive input DAC1 output, without Buffer output
P2.4/ AD2	27	DB/ AI	GPIO Input of ADC channel 2 for bus voltage sampling
P2.5/ AD3	28	DB/ AI	GPIO Input of ADC channel 3
P2.6/ C3M/ DA0/ AD11	29	DB/ AI/ AO/ AI	GPIO CMP3 negative input DAC0 output, without Buffer output Input of ADC channel 11
P2.7/ AD4/ C3P/ A0O/ C4M	30	DB/ AI/ AI/ AO/ AI	GPIO Input of ADC channel 4 for bus current sampling CMP3 positive input AMP0 output CMP4 negative input
P3.0/ A0M	31	DB/ AI	GPIO AMP0 negative input
P3.1/ A0P	32	DB/ AI	GPIO AMP0 positive input
P3.2/ AD5/ VHALF	33	DB/ AI/ AO	GPIO Input of ADC channel 5 VREF/2 output with an external 1μF capacitor
P3.3/ AD6	34	DB/ AI	GPIO Input of ADC channel 6
P3.4/ AD7/ C3PS/ C4MS	35	DB/ AI/ AI/ AI	GPIO Input of ADC channel 7 CMP3 positive input after function switching CMP4 negative input after function switching

Pin	FU6865Q QFN56	IO Type	Function Description
P3.5/ VREF	36	DB/ AB	GPIO ADC external VREF input or internal VREF output, with an external 1 $\mu$ F ~ 4.7 $\mu$ F capacitor
P4.4	37	DB	GPIO, configurable as INT1 input
P5.1	38	DB	GPIO
P3.6/ HAL2/ RXD2	39	DB/ DI/ DB	GPIO Hall-IC2 logic level input UART2 RXD input in two-wire mode or TXD output/RXD input in single-wire mode
P3.7/ HAL1/ TXD2	40	DB/ DI/ DO	GPIO Hall-IC1 logic level input UART2 TXD output
P0.0/ TIM4S/ TXD2S/ SDA	41	DO/ DB/ DB/ DO	GPIO, configurable as INT0 input Timer4 input/output after function switching UART2 TXD output after function switching I <sup>2</sup> C SDA, configured as collector open-drain output
P0.1/ DBG/ TIM4/ TIM3S/ RXD2S/  SCL	42	DB/ DO/ DB/ DB/ DB/  DB	GPIO, configurable as INT0 input Debug port Timer4 input/output Timer3 input/output after function switching UART2 RXD input in two-wire mode or TXD output/RXD input in single-wire mode after function switching I <sup>2</sup> C SCL, configured as collector open-drain output
P0.2/ LXIN/ HAL0	43	DB/ AI/ DI	GPIO, configurable as INT0 input 32768Hz crystal clock input Hall-IC0 logic level input
P0.3/ LXOUT/ PFC	44	DB/ AO/ DO	GPIO, configurable as INT0 input 32768Hz crystal clock input PFCPWM output
P0.4/ NSS	45	DB/ DB	GPIO, configurable as INT1 input SPI NSS
P0.5/ TXD/ SCLK	46	DB/ DO/ DB	GPIO, configurable as INT0 input UART1 TXD output SPI SCLK
P0.6/ RXD/ MOSI	47	DB/ DB/ DB	GPIO, configurable as INT0 input UART1 RXD input in two-wire mode or TXD output/RXD input in single-wire mode SPI MOSI, master output or slave input
P0.7/ MISO/ CXO/ TIM2S/ QEPA	48	DB/ DB/ DO/ DB/ DI	GPIO SPI MISO, master input or slave output Test port for comparator output Timer2 input/output after function switching QEP encode A input
P1.0/ TIM2/ QEPB	49	DB/ DB/ DI	GPIO, configurable as INT1 input Timer2 input/output QEP encode B input
P1.1/ TIM3	50	DB/ DB	GPIO, configurable as INT0/INT1 input Timer3 input/output
VDRV	51	P	6N pre-driver power supply, 6V~20V, with an external 1 $\mu$ F ~ 10 $\mu$ F capacitor
VSS	52	P	Ground
NC	53		Not connected
LU	54	DO	6N pre-driver low-side U-phase PWM output
LV	55	DO	6N pre-driver low-side V-phase PWM output
LW	56	DO	6N pre-driver low-side W-phase PWM output



## 2.4 FU6865Q QFN56 Pinout Diagram

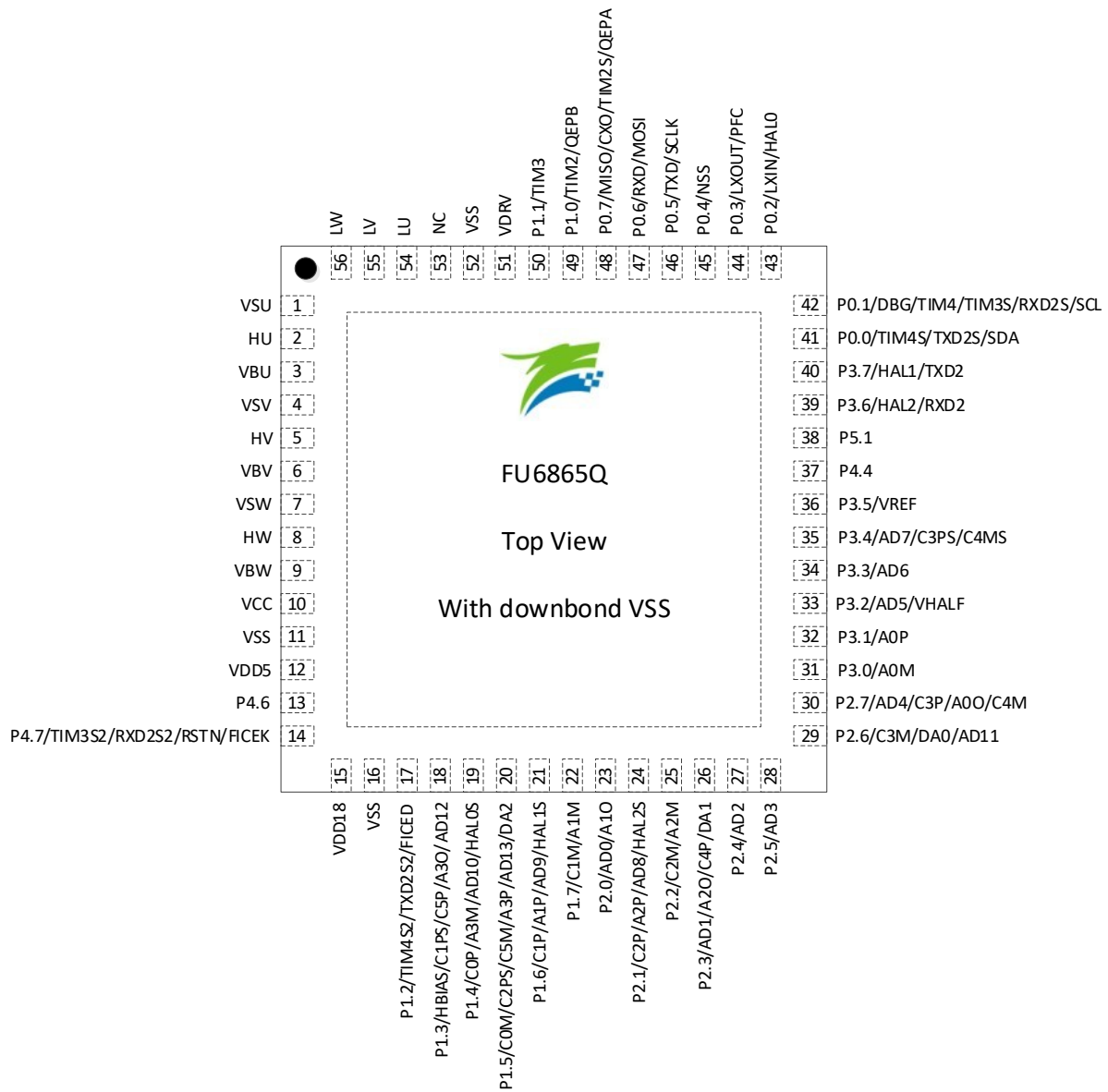


Figure 2-2 FU6865Q QFN56 Pinout Diagram21

**2.5 FU6864Q QFN48-38 Pins**

Table 2-3 FU6864Q QFN48-38 Pin Descriptions

Pin	FU6864Q QFN48-38	IO Type	Function Description
P2.1/ C2P/ A2P/ AD8/ HAL2S	1	DB/ AI/ AI/ AI/ DI	GPIO, configurable as INT1 input CMP2 positive input AMP2 positive input Input of ADC channel 8 Hall-IC2 logic level input after function switching
P2.2/ C2M/ A2M	2	DB/ AI/ AI	GPIO CMP2 negative input AMP2 negative input
P2.4/ AD2	3	DB/ AI	GPIO Input of ADC channel 2 for bus voltage sampling
P2.6/ C3M/ DA0/ AD11	4	DB/ AI/ AO/ AI	GPIO CMP3 negative input DAC0 output, without Buffer output Input of ADC channel 11
P2.7/ AD4/ C3P/ A0O/ C4M	5	DB/ AI/ AI/ AO/ AI	GPIO Input of ADC channel 4 for bus current sampling CMP3 positive input AMP0 output CMP4 negative input
P3.0/ A0M	6	DB/ AI	GPIO AMP0 negative input
P3.1/ A0P	7	DB/ AI	GPIO AMP0 positive input
P3.3/ AD6	8	DB/ AI	GPIO Input of ADC channel 6
P3.4/ AD7/ C3PS/ C4MS	9	DB/ AI/ AI/ AI	GPIO Input of ADC channel 7 CMP3 positive input after function switching CMP4 negative input after function switching
P3.5/ VREF	10	DB/ AB	GPIO ADC external VREF input or internal VREF output, with an external 1μF ~ 4.7μF capacitor
P0.0/ TIM4S/ TXD2S/ SDA	11	DO/ DB/ DO/ DO	GPIO, configurable as INT0 input Timer4 input/output after function switching UART2 TXD output after function switching I <sup>2</sup> C SDA, configured as collector open-drain output
P0.1/ DBG/ TIM4/ TIM3S/ RXD2S/  SCL	12	DB/ DO/ DB/ DB/ DB/ DB	GPIO, configurable as INT0 input Debug port Timer4 input/output Timer3 input/output after function switching UART2 RXD input in two-wire mode or TXD output/RXD input in single-wire mode after function switching I <sup>2</sup> C SCL, configured as collector open-drain output
P0.3/ PFC	13	DB/ DO	GPIO, configurable as INT0 input PFCPWM output
P1.1/ TIM3	14	DB/ DB	GPIO, configurable as INT0/INT1 input Timer3 input/output
COM	15	P	Ground
LW	16	DO	6N pre-driver low-side W-phase PWM output
LV	17	DO	6N pre-driver low-side V-phase PWM output
LU	18	DO	6N pre-driver low-side U-phase PWM output
VBU	19	P	6N pre-driver high-side U-phase bootstrap power supply
HU	20	DO	6N pre-driver high-side U-phase PWM output

Pin	FU6864Q QFN48-38	IO Type	Function Description
VSU	21	P	6N pre-driver U-phase input, as GND reference for U-phase high-side bootstrap
VSV	22	P	6N pre-driver V-phase input, as GND reference for V-phase high-side bootstrap
HV	23	DO	6N pre-driver high-side U-phase PWM output
VBV	24	P	6N pre-driver high-side V-phase bootstrap power supply
VSW	25	P	6N pre-driver W-phase input, as GND reference for W-phase high-side bootstrap
HW	26	DO	6N pre-driver high-side W-phase PWM output
VBW	27	P	6N pre-driver high-side W-phase bootstrap power supply
VCC	28	P	Power input. The voltage range is determined by VCC_MODE, with an external filter capacitor of 4.7μF or larger. <ul style="list-style-type: none"> <li>■ Single-power supply mode: When VCC_MODE = 0, external power supply 12V~20V is connected to VCC pin, and internal LDO supplies VDD5 voltage.</li> </ul>
VSS	29	P	Ground
VDD5	30	P	Internal LDO outputs 5V power supply, with an external 1μF or above capacitor.
P4.7/ TIM3S2/ RXD2S2/  RSTN/ FICEK	31	DI/ DI/ DB/  DI/ DI	GPIO, used as an input only and configured with pull-up or pull-down resistor Timer3 input after function switching UART2 RXD input in two-wire mode or TXD output/RXD input in single-wire mode after function switching Input of external reset; Built-in pull-up resistor FICE SCL
P4.5	32	DB	GPIO, configurable as INT1 input
P1.2/ TIM4S2/ TXD2S2/ FICED	33	DB/ DB/ DO/ DB	GPIO, configurable as INT1 input Timer4 input/output after function switching UART2 TXD output after function switching FICE SDA
P1.3/ HBIAS/  C1PS/ C5P/ A3O/ AD12	34	DB/ DO/  AI/ AI/ AO/ AI	GPIO, configurable as INT1 input Hall bias power supply, internally connected to VDD5 via a switch to output large current CMP1 positive input after function switching CMP5 positive input AMP3 output Input of ADC channel 12
P1.4/ C0P/ A3M/ AD10/ HAL0S	35	DB/ AI/ AI/ AI/ DI	GPIO, configurable as INT1 input CMP0 positive input AMP3 negative input Input of ADC channel 10 Hall-IC0 logic level input after function switching
P1.5/ C0M/ C2PS/ C5M A3P/ AD13/ DA2	36	DB/ AI/ AI/ AI/ AI/ AI/ AO	GPIO, configurable as INT1 input CMP0 negative input CMP2 positive input after function switching CMP5 negative input AMP3 positive input Input of ADC channel 13 DAC2 output, without buffer output
P1.6/ C1P/ A1P/ AD9/ HAL1S	37	DB/ AI/ AI/ AI/ DI	GPIO, configurable as INT1 input CMP1 positive input AMP1 positive input Input of ADC channel 9 Hall-IC1 logic level input after function switching
P1.7/ C1M/ A1M	38	DB/ AI/ AI	GPIO, configurable as INT1 input CMP1 negative input AMP1 negative input

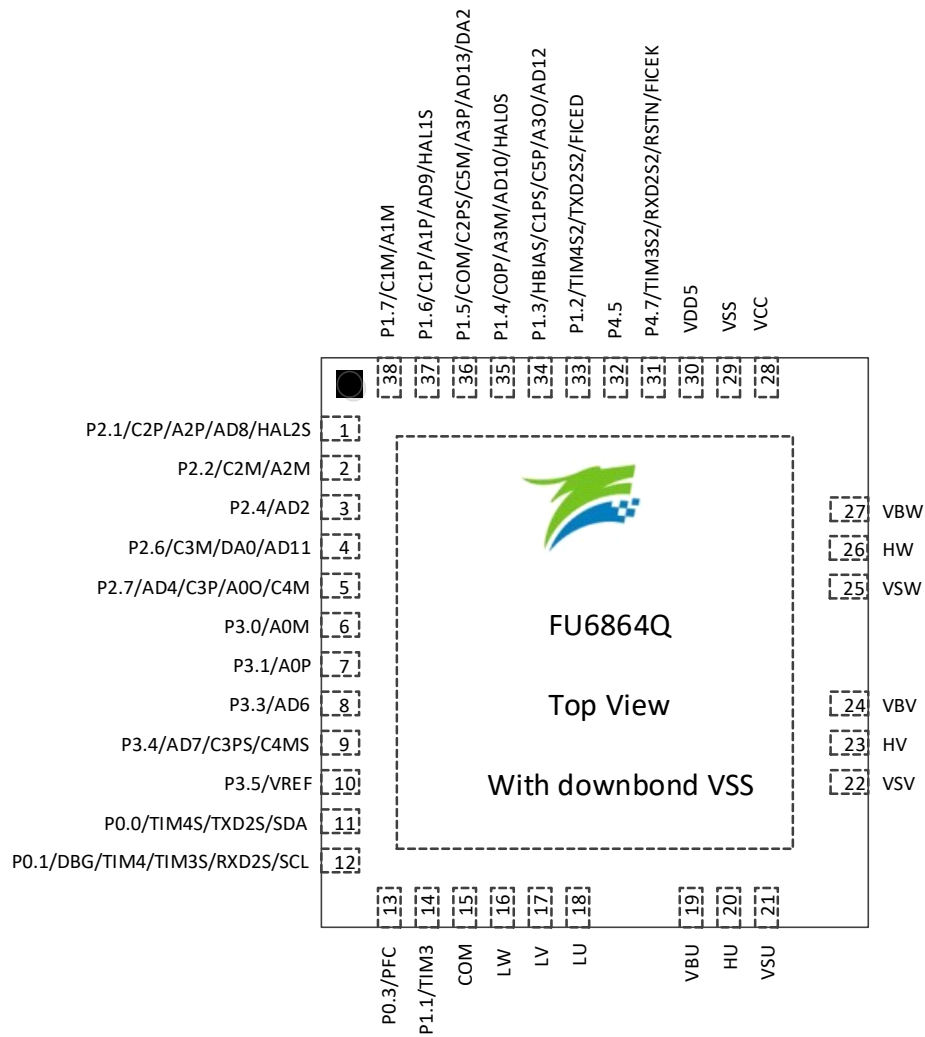
**2.6 FU6864Q QFN48-38 Pinout Diagram**


Figure 2-3 FU6864Q QFN48-38 Pinout Diagram

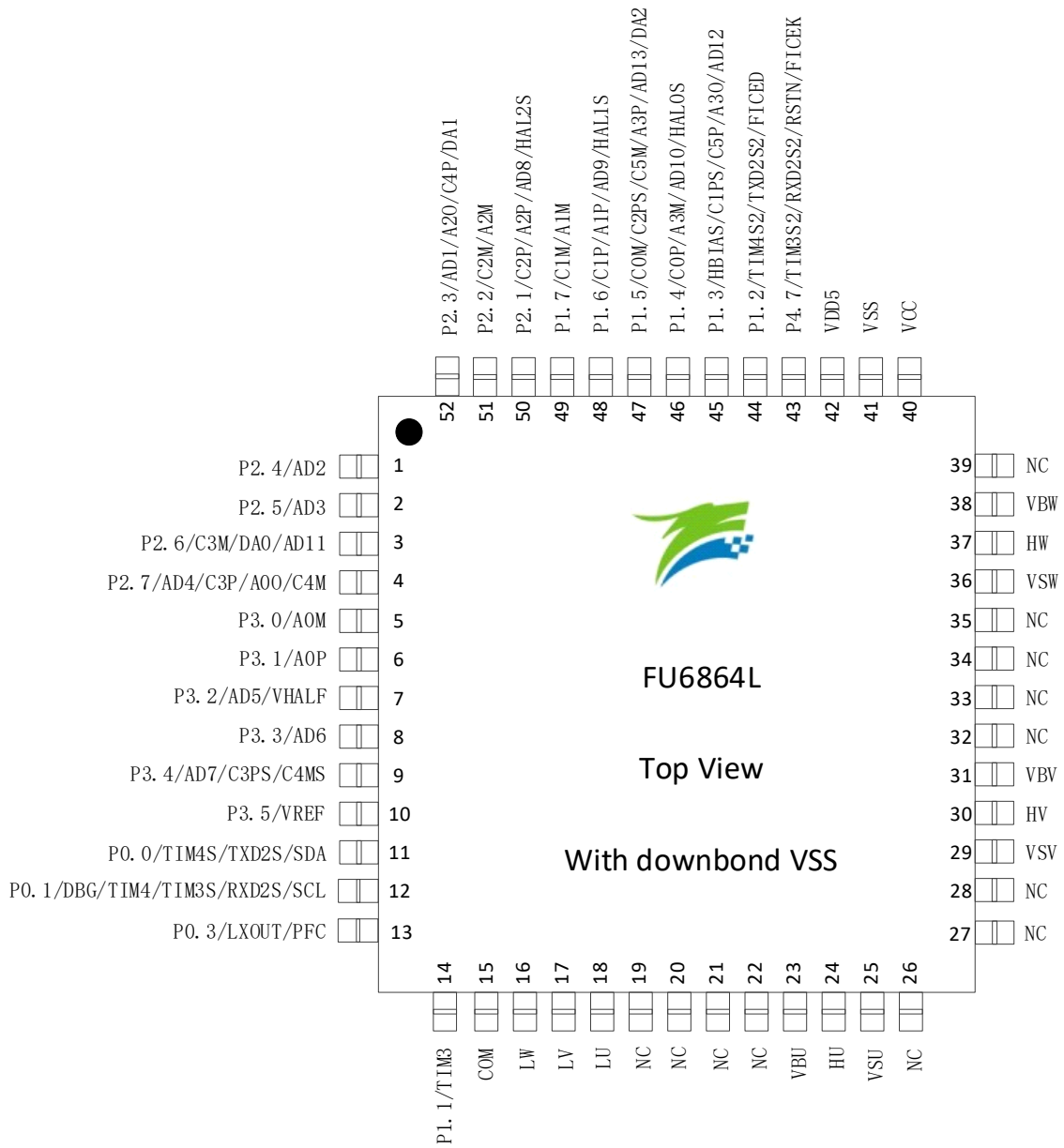
## 2.7 FU6864L LQFP52 Pins

Table 2-4 FU6864L LQFP52 Pin Descriptions

Pin	FU6864L LQFP52	IO Type	Function Description
P2.4/ AD2	1	DB/ AI	GPIO Input of ADC channel 2 for bus voltage sampling
P2.5/ AD3	2	DB/ AI	GPIO Input of ADC channel 3
P2.6/ C3M/ DA0/ AD11	3	DB/ AI/ AO/ AI	GPIO CMP3 negative input DAC0 output, without Buffer output Input of ADC channel 11
P2.7/ AD4/ C3P/ A0O/ C4M	4	DB/ AI/ AI/ AO/ AI	GPIO Input of ADC channel 4 for bus current sampling CMP3 positive input AMP0 output CMP4 negative input
P3.0/ A0M	5	DB/ AI	GPIO AMP0 negative input
P3.1/ A0P	6	DB/ AI	GPIO AMP0 positive input
P3.2/ AD5/ VHALF	7	DB/ AI/ AO	GPIO Input of ADC channel 5 VREF/2 output with an external 1 $\mu$ F capacitor
P3.3/ AD6	8	DB/ AI	GPIO Input of ADC channel 6
P3.4/ AD7/ C3PS/ C4MS	9	DB/ AI/ AI/ AI	GPIO Input of ADC channel 7 CMP3 positive input after function switching CMP4 negative input after function switching
P3.5/ VREF	10	DB/ AB	GPIO ADC external VREF input or internal VREF output, with an external 1 $\mu$ F ~ 4.7 $\mu$ F capacitor
P0.0/ TIM4S/ TXD2S/ SDA	11	DO/ DB/ DB/ DO	GPIO, configurable as INT0 input Timer4 input/output after function switching UART2 TXD output after function switching I <sup>2</sup> C SDA, configured as collector open-drain output
P0.1/ DBG/ TIM4/ TIM3S/ RXD2S/  SCL	12	DB/ DO/ DB/ DB/ DB/ DB	GPIO, configurable as INT0 input Debug port Timer4 input/output Timer3 input/output after function switching UART2 RXD input in two-wire mode or TXD output/RXD input in single-wire mode after function switching I <sup>2</sup> C SCL, configured as collector open-drain output
P0.3/ LXOUT/ PFC	13	DB/ AO/ DO	GPIO, configurable as INT0 input 32768Hz crystal clock input PFCPWM output
P1.1/ TIM3	14	DB/ DB	GPIO, configurable as INT0/INT1 input Timer3 input/output
COM	15	P	Ground
LW	16	DO	6N pre-driver low-side W-phase PWM output
LV	17	DO	6N pre-driver low-side V-phase PWM output
LU	18	DO	6N pre-driver low-side U-phase PWM output
NC	19		Not connected
NC	20		Not connected
NC	21		Not connected

Pin	FU6864L LQFP52	IO Type	Function Description
NC	22		Not connected
VBU	23	P	6N pre-driver high-side U-phase bootstrap power supply
HU	24	DO	6N pre-driver high-side U-phase PWM output
VSU	25	P	6N pre-driver U-phase input, as GND reference for U-phase high-side bootstrap
NC	26		Not connected
NC	27		Not connected
NC	28		Not connected
VSV	29	P	6N pre-driver V-phase input, as GND reference for V-phase high-side bootstrap
HV	30	DO	6N pre-driver high-side V-phase PWM output
VBV	31	P	6N pre-driver high-side V-phase bootstrap power supply
NC	32		Not connected
NC	33		Not connected
NC	34		Not connected
NC	35		Not connected
VSW	36	P	6N pre-driver W-phase input, as GND reference for W-phase high-side bootstrap
HW	37	DO	6N pre-driver high-side W-phase PWM output
VBW	38	P	6N pre-driver high-side W-phase bootstrap power supply
NC	39		Not connected
VCC	40	P	Power input. The voltage range is determined by VCC_MODE, with an external filter capacitor of 4.7 $\mu$ F or larger. <ul style="list-style-type: none"> <li>■ Single-power supply mode: When VCC_MODE = 0, external power supply 12V~20V is connected to VCC pin, and internal LDO supplies VDD5 voltage.</li> </ul>
VSS	41	P	Ground
VDD5	42	P	Internal LDO outputs 5V power supply, with an external 1 $\mu$ F or above capacitor Power input or 5V internal LDO output, which is determined by VCC_MODE, with an external filter capacitor of 1 $\mu$ F or above. See descriptions on VCC pin for details.
P4.7/ TIM3S2/ RXD2S2/  RSTN/ FICEK	43	DI/ DI/ DB/  DI/ DI	GPIO, used as an input only and configured with pull-up or pull-down resistor Timer3 input after function switching UART2 RXD input in two-wire mode or TXD output/RXD input in single-wire mode after function switching Input of external reset; Built-in pull-up resistor FICE SCL
P1.2/ TIM4S2/ TXD2S2/ FICED	44	DB/ DB/ DO/ DB	GPIO, configurable as INT1 input Timer4 input/output after function switching UART2 TXD output after function switching FICE SDA
P1.3/ HBIAS/  C1PS/ C5P/ A3O/ AD12	45	DB/ DO/  AI/ AI/ DO/ AI	GPIO, configurable as INT1 input Hall bias power supply, internally connected to VDD5 via a switch to output large current CMP1 positive input after function switching CMP5 positive input AMP3 output Input of ADC channel 12
P1.4/ C0P/ A3M/ AD10/ HAL0S	46	DB/ AI/ AI/ AI/ DI	GPIO, configurable as INT1 input CMP0 positive input AMP3 negative input Input of ADC channel 10 Hall-IC0 logic level input after function switching
P1.5/ C0M/ C2PS/ C5M/ A3P/	47	DB/ AI/ AI/ AI/ AI/	GPIO, configurable as INT1 input CMP0 negative input CMP2 positive input after function switching CMP5 negative input AMP3 positive input

Pin	FU6864L LQFP52	IO Type	Function Description
AD13/ DA2		AI/ AO	Input of ADC channel 13 DAC2 output, without buffer output
P1.6/ C1P/ A1P/ AD9/ HAL1S	48	DB/ AI/ AI/ AI/ DI	GPIO, configurable as INT1 input CMP1 positive input AMP1 positive input Input of ADC channel 9 Hall-IC1 logic level input after function switching
P1.7/ C1M/ A1M	49	DB/ AI/ AI	GPIO, configurable as INT1 input CMP1 negative input AMP1 negative input
P2.1/ C2P/ A2P/ AD8/ HAL2S	50	DB/ AI/ AI/ AI/ DI	GPIO CMP2 positive input AMP2 positive input Input of ADC channel 8 Hall-IC2 logic level input after function switching
P2.2/ C2M/ A2M	51	DB/ AI/ AI	GPIO CMP2 negative input AMP2 negative input
P2.3/ AD1/ A2O/ C4P/ DA1	52	DB/ AI/ AO/ AI/ DO	GPIO Input of ADC channel 1 AMP2 output CMP4 positive input DAC1 output, without Buffer output

**2.8 FU6864L LQFP52 Pinout Diagram**

**Figure 2-4 FU6864L LQFP52 Pinout Diagram**



### 3 Package Information

#### 3.1 LQFP48\_7X7 (FU6815L)

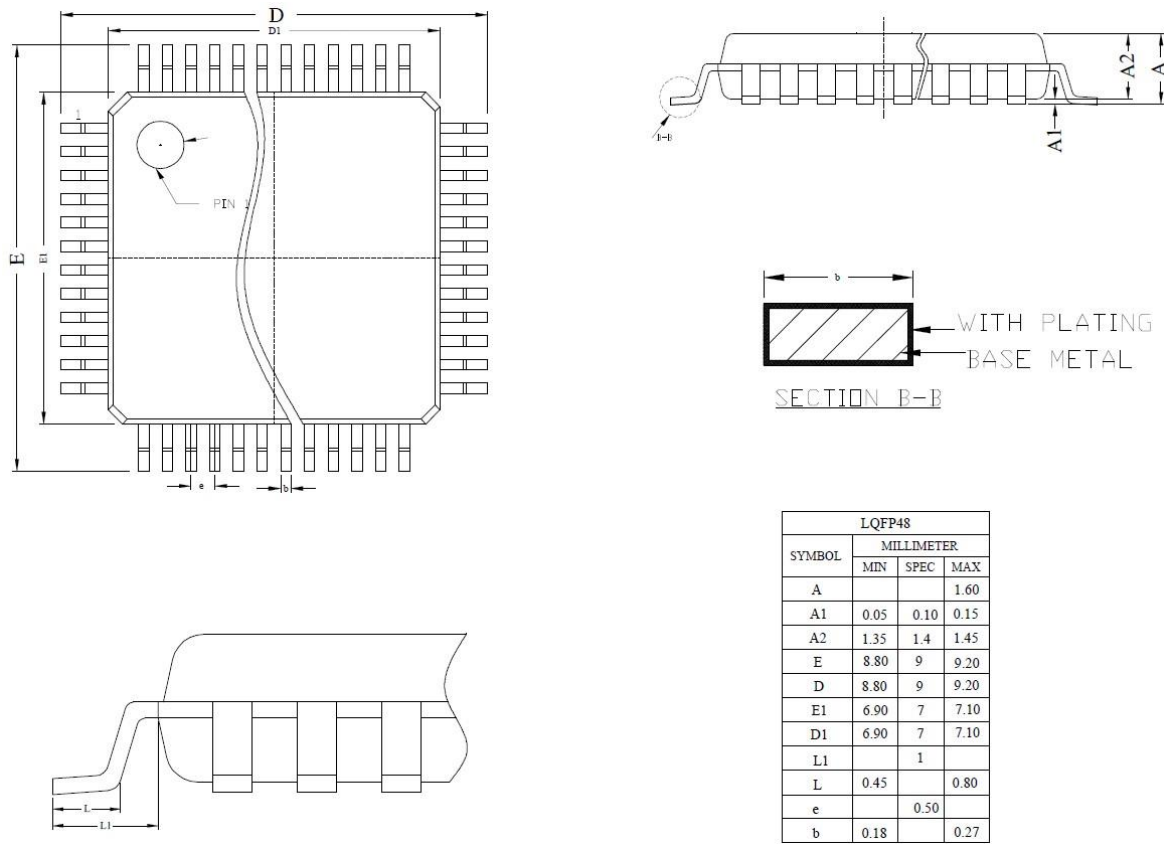


Figure 3-1 LQFP48\_7X7 Package Drawings and Dimensions

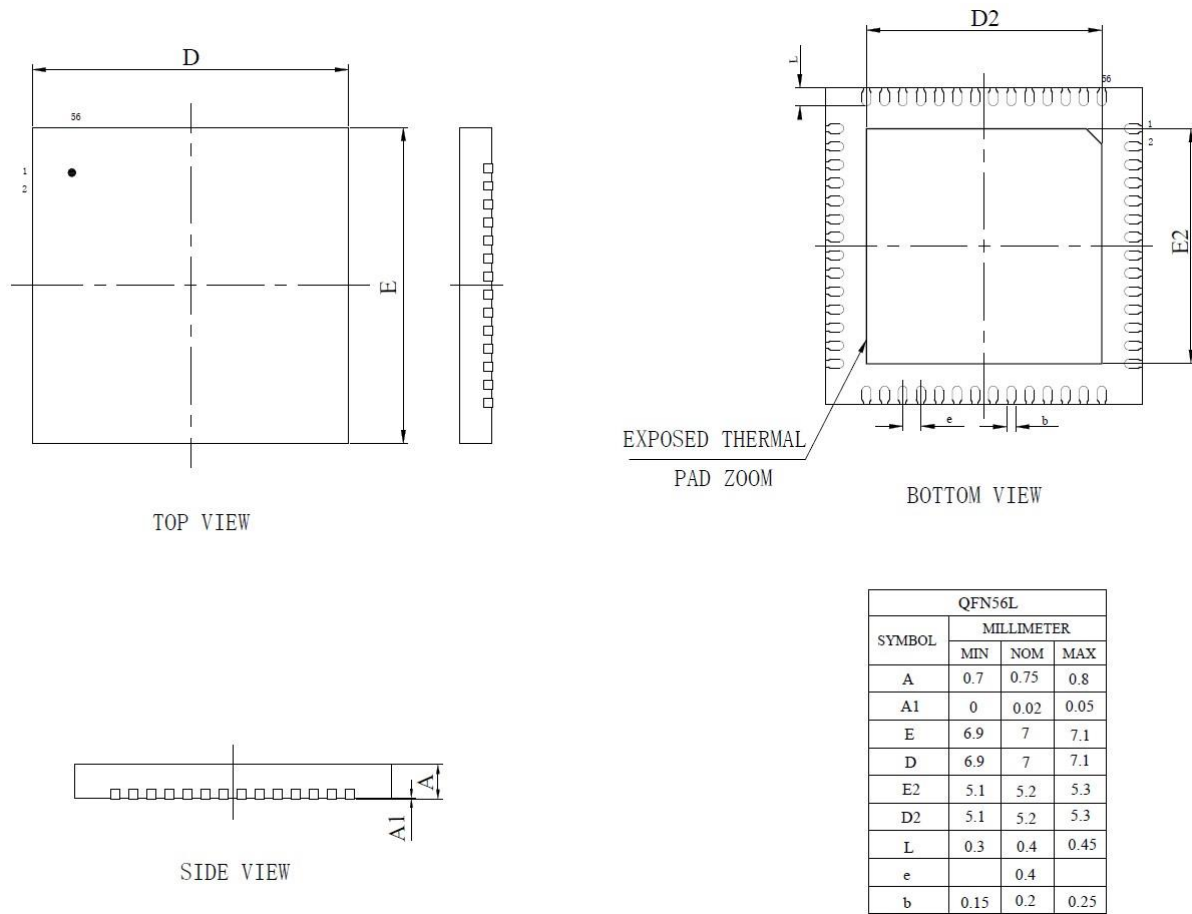
**3.2 QFN56\_7X7 (FU6865Q)**


Figure 3-2 QFN56\_7X7 Package Drawings and Dimensions

3.3 QFN48-38\_7X7 (FU6864Q)

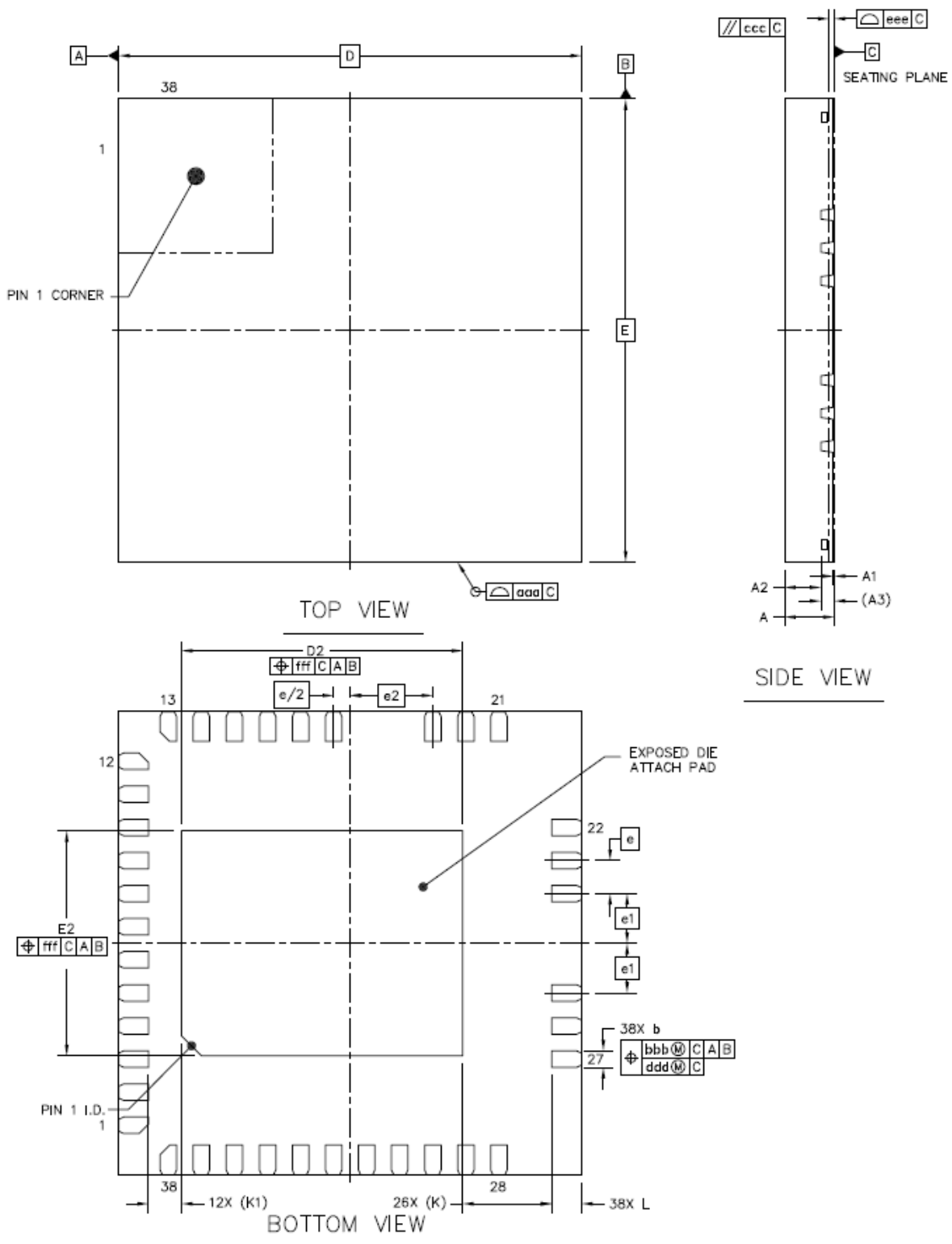


Figure 3-3 QFN48-38\_7X7 Package Drawings

Table 3-1 QFN48-38\_7X7 Package Dimensions

Symbol	Dimensions In Millimeter		
	Min.	Nom.	Max.
A	0.70	0.75	0.80
A1	0	0.02	0.05
A2	-	0.55	-
A3	0.203 REF		
b	0.20	0.25	0.30
D	7 BSC		
E	7 BSC		
e	0.5 BSC		
e1	0.75 BSC		
e2	1.25 BSC		
D2	4.15	4.25	4.35
E2	3.30	3.40	3.50
L	0.35	0.45	0.55
K	1.35 REF		
K1	0.5 REF		
aaa	0.10		
ccc	0.10		
eee	0.08		
bbb	0.10		
ddd	0.05		
fff	0.10		

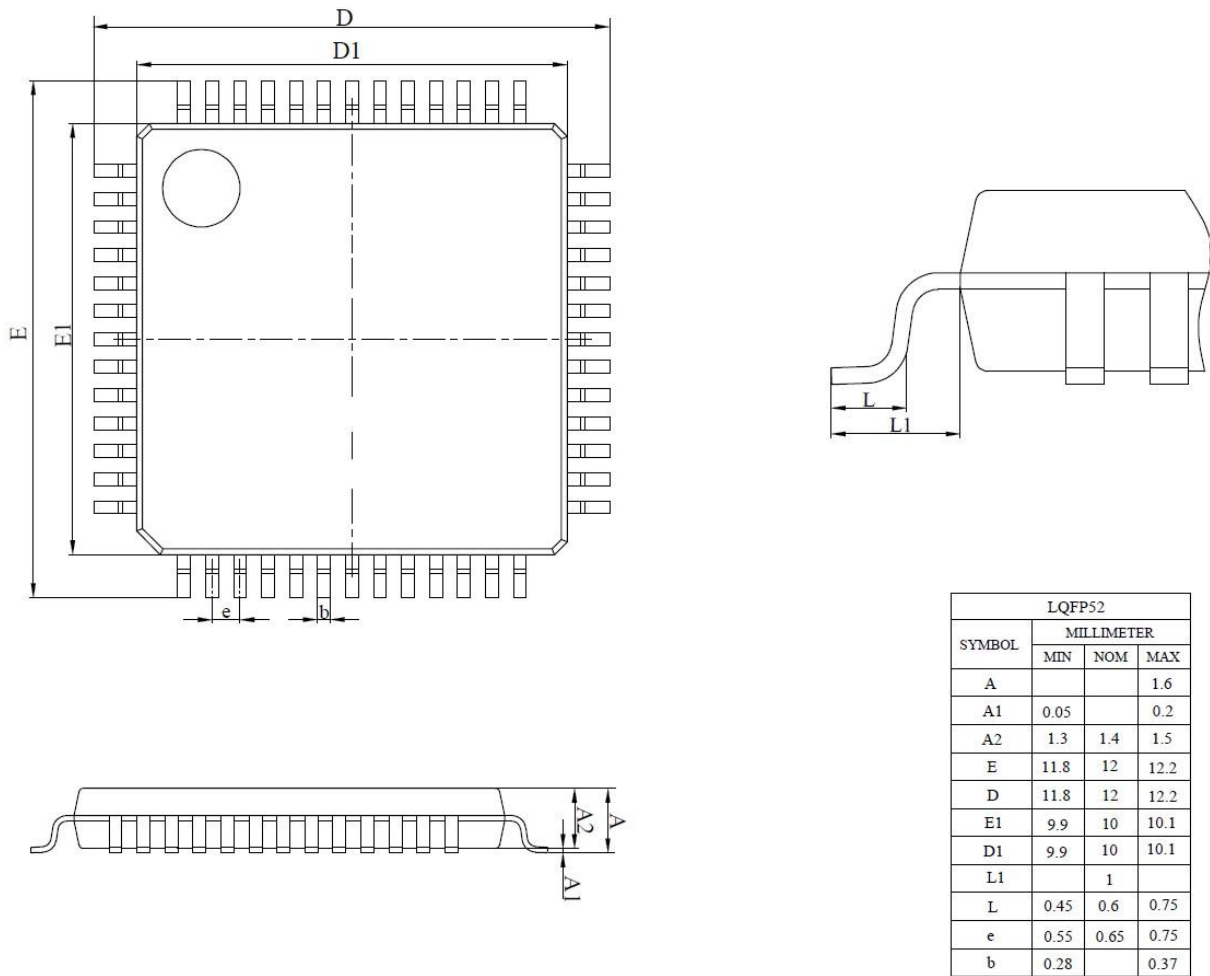
**3.4 LQFP52\_10X10 (FU6864L)**


Figure 3-4 LQFP52\_10X10 Package Drawings and Dimensions

**4 Ordering Information**

Table 4-1 Model Selections

Model	MIPS (Peak)	Flash (kByte)	XRAM (kByte)	Clock Circuit			Driver Interface		Driver Type		I <sup>2</sup> C/UART/SPI	DMA	GPIO	Timer	Analog Peripherals							Lead-free	Package	
				Internal Fast Clock	Internal Slow Clock	External Slow Clock	6NPre-driver	PWM	Square Wave	FOC					ADC			DAC		VREF	Operational Amplifier			Comparator
															Number	Channel	Bits	Number	Bits					
FU6815L	24	32	3.75	√	√	√	-	√	√	√	√	38	6	1	14	12	3	9\8\6	√	4	4	√	LQFP48 (7x7mm)	
FU6865Q	24	32	3.75	√	√	√	√	-	√	√	√	36	6	1	14	12	3	9\8\6	√	4	4	√	QFN56 (7x7mm)	
FU6864Q	24	32	3.75	√	√	-	√	-	√	√	I <sup>2</sup> C/UART	√	22	6	1	12	12	3	9\8\6	√	4	4	√	QFN48-38 (7x7mm)
FU6864L	24	32	3.75	√	√	-	√	-	√	√	I <sup>2</sup> C/UART	√	24	6	1	13	12	3	9\8\6	√	4	4	√	LQFP52 (10X10mm)

## 5 Electrical Characteristics

### 5.1 Absolute Maximum Ratings

#### 5.1.1 FU6815L

Table 5-1 FU6815L Absolute Maximum Ratings

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Operating Junction Temperature $T_J$		-40	-	150	°C
Storage Temperature $T_{stg}$		-55	-	150	°C
VCC to VSS Voltage		-0.3	-	38	V
VDD5 to VSS Voltage		-0.3	-	6.5	V
RSTN/GPIO to VSS Voltage		-0.3	-	VDD5 + 0.3	V

#### 5.1.2 FU6865Q

Table 5-2 FU6865Q Absolute Maximum Ratings

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Operating Junction Temperature $T_J$		-40	-	150	°C
Storage Temperature $T_{stg}$		-55	-	150	°C
VCC to VSS Voltage		-0.3	-	38	V
VDD5 to VSS Voltage		-0.3	-	6.5	V
RSTN/GPIO to VSS Voltage		-0.3	-	VDD5 + 0.3	V
VDRV to VSS Voltage		-0.3	-	22	V
Low-side Output Voltage $V_{LU, LV, LW}$		-0.3	-	VDRV + 0.3	V
High-side Floating Voltage $V_{BU, BV, BW}$		-0.3	-	165	V
High-side Floating Offset Voltage $V_{SU, SV, SW}$		$V_{BU, BV, BW} - 22$	-	$V_{BU, BV, BW} + 0.3$	V
High-side Output Voltage $V_{HU, HV, HW}$		$V_{SU, SV, SW} - 0.3$	-	$V_{BU, BV, BW} + 0.3$	V

#### 5.1.3 FU6864Q

Table 5-3 FU6864Q Absolute Maximum Ratings

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Operating Junction Temperature $T_J$		-40	-	150	°C
Storage Temperature $T_{stg}$		-55	-	150	°C
VCC to VSS Voltage		-0.3	-	22	V
VDD5 to VSS Voltage		-0.3	-	6.5	V
High-side Floating Voltage $V_{BU, BV, BW}$		-0.3	-	625	V
Low-side Supply Voltage		-0.3	-	VCC	V
Low-side Output Voltage $V_{LU, LV, LW}$		-0.3	-	VCC + 0.3	V
RSTN/GPIO to VSS Voltage		-0.3	-	VDD5 + 0.3	V

### 5.1.4 FU6864L

Table 5-4 FU6864L Absolute Maximum Ratings

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Operating Junction Temperature $T_J$		-40	-	150	°C
Storage Temperature $T_{stg}$		-55	-	150	°C
VCC to VSS Voltage		-0.3	-	22	V
VDD5 to VSS Voltage		-0.3	-	6.5	V
High-side Floating Voltage $V_{BU, BV, BW}$		-0.3	-	625	V
Low-side Supply Voltage		-0.3	-	VCC	V
Low-side Output Voltage $V_{LU, LV, LW}$		-0.3	-	VCC + 0.3	V
RSTN/GPIO to VSS Voltage		-0.3	-	VDD5 + 0.3	V

Note: Stress values greater than "Absolute Maximum Ratings" listed in above tables may cause irremediable damages to the device. These are stress ratings only, and it is NOT recommended to use your device in conditions that go beyond these stress ratings. Exposure to "Absolute Maximum Ratings" for extended periods may affect device reliability.

## 5.2 Global Electrical Characteristics

### 5.2.1 FU6815L

Table 5-5 FU6815L Global Electrical Characteristics

( $T_A = 25^\circ\text{C}$  and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VCC Operating Voltage <sup>[1]</sup>	High-voltage single-power supply mode and $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	5	-	28	V
	Dual-power supply mode <sup>[2]</sup> , VCC_MODE = 1, VCC $\geq$ VDD5 and $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	5	-	36	V
VDD5 Operating Voltage	VCC_MODE = 1 and VCC pin is connected with VDD5 pin <sup>[2]</sup>	3	-	5.5	V
I <sub>VCC</sub> Operating Current <sup>[3]</sup>		-	15	-	mA
I <sub>VCC</sub> Standby Current <sup>[3]</sup>		-	6	-	mA
I <sub>VCC</sub> Sleep-mode Current	VCC = 12V	-	50	150	μA

### 5.2.2 FU6865Q

Table 5-6 FU6865Q Global Electrical Characteristics

( $T_A = 25^\circ\text{C}$ , VCC = VDRV = 15V and VCC\_MODE = 0 unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VCC Operating Voltage <sup>[1]</sup>	High-voltage single-power supply mode and $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	5	-	28	V
	Dual-power supply mode <sup>[2]</sup> , VCC_MODE = 1, VCC $\geq$ VDD5 and $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	5	-	36	V
VDD5 Operating Voltage	VCC_MODE = 1 and VCC pin is connected with VDD5 pin <sup>[2]</sup>	3	-	5.5	V



Parameter	Test Conditions	Min.	Typ.	Max.	Unit
I <sub>VCC</sub> Operating Current <sup>[3]</sup>		-	20	-	mA
I <sub>VCC</sub> Standby Current <sup>[3]</sup>		-	7	-	mA
I <sub>VCC</sub> Sleep-mode Current		-	850	1650	μA

### 5.2.3 FU6864Q

Table 5-7 FU6864Q Global Electrical Characteristics

(T<sub>A</sub> = 25°C and VCC = 12V ~ 20V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VCC Operating Voltage <sup>[1]</sup>		12	-	20	V
V <sub>BU</sub> , V <sub>BV</sub> , V <sub>BW</sub> Floating Voltage		-	-	600	V
V <sub>BU,BV,BW</sub> to V <sub>SU,SV,SW</sub> Voltage		-	-	18	V
I <sub>VCC</sub> Operating Current <sup>[3]</sup>		-	24	-	mA
I <sub>VCC</sub> Standby Current <sup>[3]</sup>		-	6	-	mA
I <sub>VCC</sub> Sleep-mode Current	VCC = 12V	-	210	-	μA
Operating Ambient Temperature T <sub>A</sub>		-40	-	85	°C

### 5.2.4 FU6864L

Table 5-8 FU6864L Global Electrical Characteristics

(T<sub>A</sub> = 25°C and VCC = 12V ~ 20V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VCC Operating Voltage <sup>[1]</sup>		12	-	20	V
V <sub>BU</sub> , V <sub>BV</sub> , V <sub>BW</sub> Floating Voltage		-	-	600	V
V <sub>BU,BV,BW</sub> to V <sub>SU,SV,SW</sub> Voltage		-	-	18	V
I <sub>VCC</sub> Operating Current <sup>[3]</sup>		-	24	-	mA
I <sub>VCC</sub> Standby Current <sup>[3]</sup>		-	6	-	mA
I <sub>VCC</sub> Sleep-mode Current	VCC = 12V	-	210	-	μA
Operating Ambient Temperature T <sub>A</sub>		-40	-	85	°C

Notes:

[1] VCC voltage rise rate ranges from 0.5V/μs to 0.1V/s depending on samples batches.

[2] VDD5 must be in the range of 5V~5.5V during Flash write or erase.

[3] Characteristics may vary with different configurations.

### 5.3 GPIO Electrical Characteristics

#### 5.3.1 FU6815L

Table 5-9 FU6815L GPIO Electrical Characteristics

( $T_A = 25^\circ\text{C}$  and  $V_{CC} = 5\text{V} \sim 28\text{V}$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Output Rise Time	50pF load, from 10% to 90%, $T_A = 25^\circ\text{C}$	-	15	-	ns
Output Fall Time	50pF load, from 90% to 10%, $T_A = 25^\circ\text{C}$	-	13	-	ns
$V_{OH}$ Output High Voltage	$I_{OH} = 4\text{mA}$ , $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	$V_{DD5} - 0.7$	-	-	V
$V_{OL}$ Output Low Voltage	$I_{OL} = 4\text{mA}$ , $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	-	-	$V_{SS} + 0.7$	V
$V_{IH}$ Input High Voltage <sup>[1]</sup>		$0.7 * V_{DD5}$	-	-	V
$V_{IL}$ Input Low Voltage		-	-	$0.2 * V_{DD5}$	V
Pull-up Resistor <sup>[2]</sup>		-	33	-	k $\Omega$
Pull-up Resistor <sup>[3]</sup>		-	5.6	-	k $\Omega$
Pull-down Resistor <sup>[4]</sup>		-	30	-	k $\Omega$

#### 5.3.2 FU6865Q

Table 5-10 FU6865Q GPIO Electrical Characteristics

( $T_A = 25^\circ\text{C}$  and  $V_{CC} = 5\text{V} \sim 28\text{V}$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Output Rise Time	50pF load, from 10% to 90%, $T_A = 25^\circ\text{C}$	-	15	-	ns
Output Fall Time	50pF load, from 90% to 10%, $T_A = 25^\circ\text{C}$	-	13	-	ns
$V_{OH}$ Output High Voltage	$I_{OH} = 4\text{mA}$ , $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	$V_{DD5} - 0.7$	-	-	V
$V_{OL}$ Output Low Voltage	$I_{OL} = 4\text{mA}$ , $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	-	-	$V_{SS} + 0.7$	V
$V_{IH}$ Input High Voltage <sup>[1]</sup>		$0.7 * V_{DD5}$	-	-	V
$V_{IL}$ Input Low Voltage		-	-	$0.2 * V_{DD5}$	V
Pull-up Resistor <sup>[2]</sup>		-	33	-	k $\Omega$
Pull-up Resistor <sup>[3]</sup>		-	5.6	-	k $\Omega$
Pull-down Resistor <sup>[4]</sup>		-	30	-	k $\Omega$

Notes:

[1] When  $V_{DD5} = 5\text{V}$ , minimum value of  $V_{IH}$  is  $0.6 * V_{DD5}$ ;

[2] GPIOs except P0[2:0], P1[6:3], P2[1] and P3[7:6];

[3] P0[2:0], P1[6:3], P2[1] and P3[7:6];

[4] P0[1], P1[1] and P4[7]

### 5.3.3 FU6864Q

Table 5-11 FU6864Q GPIO Electrical Characteristics

( $T_A = 25^\circ\text{C}$  and  $V_{CC} = 12\text{V} \sim 20\text{V}$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Output Rise Time	50pF load, from 10% to 90%, $T_A = 25^\circ\text{C}$	-	15	-	ns
Output Fall Time	50pF load, from 90% to 10%, $T_A = 25^\circ\text{C}$	-	13	-	ns
$V_{OH}$ Output High Voltage	$I_{OH} = 4\text{mA}$ , $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	$V_{DD5} - 0.7$	-	-	V
$V_{OL}$ Output Low Voltage	$I_{OL} = 4\text{mA}$ , $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	-	-	$V_{SS} + 0.7$	V
$V_{IH}$ Input High Voltage <sup>[1]</sup>		$0.7 * V_{DD5}$	-	-	V
$V_{IL}$ Input Low Voltage		-	-	$0.2 * V_{DD5}$	V
Pull-up Resistor <sup>[2]</sup>	$V_{DD5} = 5\text{V}$	-	33	-	k $\Omega$
Pull-up Resistor <sup>[3]</sup>	$V_{DD5} = 5\text{V}$	-	5.6	-	k $\Omega$
Pull-down Resistor <sup>[4]</sup>	$V_{DD5} = 5\text{V}$	-	30	-	k $\Omega$

Notes:

[1] When  $V_{DD5} = 5\text{V}$ , minimum value of  $V_{IH}$  is  $0.6 * V_{DD5}$ ;

[2] GPIOs except P0[1:0], P1[6:3], P1[1] and P2[1]

[3] P0[1:0], P1[6:3] and P2[1]

[4] P0[1], P1[1] and P4[7]

### 5.3.4 FU6864L

Table 5-12 FU6864L GPIO Electrical Characteristics

( $T_A = 25^\circ\text{C}$  and  $V_{CC} = 12\text{V} \sim 20\text{V}$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Output Rise Time	50pF load, from 10% to 90%, $T_A = 25^\circ\text{C}$	-	15	-	ns
Output Fall Time	50pF load, from 90% to 10%, $T_A = 25^\circ\text{C}$	-	13	-	ns
$V_{OH}$ Output High Voltage	$I_{OH} = 4\text{mA}$ , $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	$V_{DD5} - 0.7$	-	-	V
$V_{OL}$ Output Low Voltage	$I_{OL} = 4\text{mA}$ , $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	-	-	$V_{SS} + 0.7$	V
$V_{IH}$ Input High Voltage <sup>[1]</sup>		$0.7 * V_{DD5}$	-	-	V
$V_{IL}$ Input Low Voltage		-	-	$0.2 * V_{DD5}$	V
Pull-up Resistor <sup>[2]</sup>	$V_{DD5} = 5\text{V}$	-	33	-	k $\Omega$
Pull-up Resistor <sup>[3]</sup>	$V_{DD5} = 5\text{V}$	-	5.6	-	k $\Omega$
Pull-down Resistor <sup>[4]</sup>	$V_{DD5} = 5\text{V}$	-	30	-	k $\Omega$

Notes:

[1] When  $V_{DD5} = 5\text{V}$ , minimum value of  $V_{IH}$  is  $0.6 * V_{DD5}$ ;

[2] GPIOs except P0[1:0], P1[6:3], P1[1] and P2[1]

[3] P0[1:0], P1[6:3] and P2[1]

[4] P0[1], P1[1] and P4[7]

## 5.4 PWM IO Electrical Characteristics (FU6815L)

### 5.4.1 FU6815L

Table 5-13 FU6815L PWM IO Electrical Characteristics

( $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 15\text{V}$  and  $V_{CC\_MODE}=0$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Output Source Current	P1_AN[HDIO] = 1	30	50	-	mA
Output Sink Current	P1_AN[HDIO] = 1	60	100	-	mA
Output Rise Time	50pF load, from 10% to 90%, $T_A = 25^\circ\text{C}$	-	18	-	ns
Output Fall Time	50pF load, from 90% to 10%, $T_A = 25^\circ\text{C}$	-	12	-	ns

## 5.5 Pre-driver IO Electrical Characteristics (FU6865Q/FU6864Q/FU6864L)

### 5.5.1 FU6865Q

Table 5-14 FU6865Q Pre-driver IO Electrical Characteristics

( $T_A = 25^\circ\text{C}$ ,  $V_{CC} = V_{DRV} = 15\text{V}$  and  $V_{CC\_MODE} = 0$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
High-level Peak Output Current		-	0.8	-	A
Low-level Peak Output Current		-	0.8	-	A
VDRV Operating Voltage		6	-	20	V
High-side Floating Voltage $V_{BU, BV, BW}$		-0.3	-	140	V
High-side Floating Offset Voltage $V_{SU, SV, SW}$		$V_{BU, BV, BW} - 20$	-	$V_{BU, BV, BW} - 6$	V
VDRV UVLO Threshold Voltage		4.3	4.8	5.3	V
VDRV UVLO Turn-off Voltage		4	4.5	5	V
VDRV UVLO Hysteresis Voltage		0.2	0.3	-	V
Output Rise Time	1nF load, from 10% to 90%	-	30	70	ns
Output Fall Time	1nF load, from 90% to 10%	-	30	70	ns
Deadtime	DT	-	100	-	ns

### 5.5.2 FU6864Q

Table 5-15 FU6864Q Pre-driver IO Electrical Characteristics

( $T_A = 25^\circ\text{C}$  and  $V_{CC} = 15\text{V}$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
High-level Peak Output Current		-	0.21	-	A
Low-level Peak Output Current		-	0.36	-	A
VCC Supply Voltage		12	-	20	V
VCC Quiescent Current		-	0.14	-	mA

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VCC UVLO Threshold Voltage		8.1	9.0	9.9	V
VCC UVLO Turn-off Voltage		7.5	8.4	9.3	V
VCC UVLO Hysteresis Voltage		0.4	0.6	-	V
Output Rise Time	1nF load, from 10% to 90%	-	90	-	ns
Output Fall Time	1nF load, from 90% to 10%	-	50	-	ns
Deadtime	DT	-	500	-	ns

### 5.5.3 FU6864L

Table 5-16 FU6864L Pre-driver IO Electrical Characteristics

(T<sub>A</sub> = 25°C and VCC = 15V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
High-level Peak Output Current		-	0.21	-	A
Low-level Peak Output Current		-	0.36	-	A
VCC Supply Voltage		12	-	20	V
VCC Quiescent Current		-	0.14	-	mA
VCC UVLO Threshold Voltage		8.1	9.0	9.9	V
VCC UVLO Turn-off Voltage		7.5	8.4	9.3	V
VCC UVLO Hysteresis Voltage		0.4	0.6	-	V
Output Rise Time	1nF load, from 10% to 90%	-	90	-	ns
Output Fall Time	1nF load, from 90% to 10%	-	50	-	ns
Deadtime	DT	-	500	-	ns

## 5.6 ADC Electrical Characteristics

### 5.6.1 FU6815L

Table 5-17 FU6815L ADC Electrical Characteristics

(T<sub>A</sub> = 25°C and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
INL (Integral Nonlinearity)	12-bit	-	2	-	LSB
DNL (Differential Nonlinearity)	12-bit	-	1.5	-	LSB
OFFSET (Offset Error)	12-bit	-	6	-	LSB
SNR (Signal-to-noise Ratio)	f <sub>IN</sub> = 350kHz	-	70.8	-	dB
ENOB (Effective Number of Bits)	f <sub>IN</sub> = 350kHz	-	10.5	-	Bit
SFDR (Spurious-free Dynamic Range)	f <sub>IN</sub> = 350kHz	-	68.2	-	dB
THD (Total Harmonic Distortion)	f <sub>IN</sub> = 350kHz	-	67	-	dB
R <sub>IN</sub> Input Resistance		-	800	-	Ω
C <sub>IN</sub> Input Capacitance		-	30	-	pF
Conversion Time		-	13	-	ADCLK <sup>[1]</sup>
Sampling Time		3	-	63	ADCLK <sup>[1]</sup>

## 5.6.2 FU6865Q

Table 5-18 FU6865Q ADC Electrical Characteristics

( $T_A = 25^\circ\text{C}$  and  $V_{CC} = 5\text{V} \sim 28\text{V}$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
INL (Integral Nonlinearity)	12-bit	-	2	-	LSB
DNL (Differential Nonlinearity)	12-bit	-	1.5	-	LSB
OFFSET (Offset Error)	12-bit	-	6	-	LSB
SNR (Signal-to-noise Ratio)	$f_{IN} = 350\text{kHz}$	-	70.8	-	dB
ENOB (Effective Number of Bits)	$f_{IN} = 350\text{kHz}$	-	10.5	-	Bit
SFDR (Spurious-free Dynamic Range)	$f_{IN} = 350\text{kHz}$	-	68.2	-	dB
THD (Total Harmonic Distortion)	$f_{IN} = 350\text{kHz}$	-	67	-	dB
$R_{IN}$ Input Resistance		-	800	-	$\Omega$
$C_{IN}$ Input Capacitance		-	30	-	pF
Conversion Time		-	13	-	ADCLK <sup>[1]</sup>
Sampling Time		3	-	63	ADCLK <sup>[1]</sup>

## 5.6.3 FU6864Q

Table 5-19 FU6864Q ADC Electrical Characteristics

( $T_A = 25^\circ\text{C}$  and  $V_{CC} = 12\text{V} \sim 20\text{V}$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
INL (Integral Nonlinearity)	12-bit	-	2	-	LSB
DNL (Differential Nonlinearity)	12-bit	-	1.5	-	LSB
OFFSET (Offset Error)	12-bit	-	6	-	LSB
SNR (Signal-to-noise Ratio)	$f_{IN} = 350\text{kHz}$	-	70.8	-	dB
ENOB (Effective Number of Bits)	$f_{IN} = 350\text{kHz}$	-	10.5	-	Bit
SFDR (Spurious-free Dynamic Range)	$f_{IN} = 350\text{kHz}$	-	68.2	-	dB
THD (Total Harmonic Distortion)	$f_{IN} = 350\text{kHz}$	-	67	-	dB
$R_{IN}$ Input Resistance		-	800	-	$\Omega$
$C_{IN}$ Input Capacitance		-	30	-	pF
Conversion Time		-	13	-	ADCLK <sup>[1]</sup>
Sampling Time		3	-	63	ADCLK <sup>[1]</sup>

## 5.6.4 FU6864L

Table 5-20 FU6864L ADC Electrical Characteristics

( $T_A = 25^\circ\text{C}$  and  $V_{CC} = 12\text{V} \sim 20\text{V}$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
INL (Integral Nonlinearity)	12-bit	-	2	-	LSB
DNL (Differential Nonlinearity)	12-bit	-	1.5	-	LSB
OFFSET (Offset Error)	12-bit	-	6	-	LSB
SNR (Signal-to-noise Ratio)	$f_{IN} = 350\text{kHz}$	-	70.8	-	dB
ENOB (Effective Number of Bits)	$f_{IN} = 350\text{kHz}$	-	10.5	-	Bit

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
SFDR (Spurious-free Dynamic Range)	$f_{IN} = 350\text{kHz}$	-	68.2	-	dB
THD (Total Harmonic Distortion)	$f_{IN} = 350\text{kHz}$	-	67	-	dB
$R_{IN}$ Input Resistance		-	800	-	$\Omega$
$C_{IN}$ Input Capacitance		-	30	-	pF
Conversion Time		-	13	-	ADCLK <sup>[1]</sup>
Sampling Time		3	-	63	ADCLK <sup>[1]</sup>

Note:

[1] ADCLK = 12MHz

## 5.7 VREF and VHALF Electrical Characteristics

### 5.7.1 FU6815L

Table 5-21 FU6815L VREF and VHALF Electrical Characteristics

( $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$  and  $V_{CC} = 5\text{V} \sim 28\text{V}$ )

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VREF	VREF_CR[VREFVSEL] = 00	4.3	4.5	4.7	V
	VREF_CR[VREFVSEL] = 01	-	VDD5	-	V
	VREF_CR[VREFVSEL] = 11	-	4	-	V
	VREF_CR[VREFVSEL] = 10	-	3	-	V
VHALF	VREF_CR[VHALFSEL] = 00	-	VREF/8	-	V
	VREF_CR[VHALFSEL] = 01	-	VREF/4	-	V
	VREF_CR[VHALFSEL] = 10	-	25*VREF/64	-	V
	VREF_CR[VHALFSEL] = 11	VREF/2 - 0.2	VREF/2	VREF/2 + 0.2	V

### 5.7.2 FU6865Q

Table 5-22 FU6865Q VREF and VHALF Electrical Characteristics

( $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$  and  $V_{CC} = 5\text{V} \sim 28\text{V}$ )

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VREF	VREF_CR[VREFVSEL] = 00	4.3	4.5	4.7	V
	VREF_CR[VREFVSEL] = 01	-	VDD5	-	V
	VREF_CR[VREFVSEL] = 11	-	4	-	V
	VREF_CR[VREFVSEL] = 10	-	3	-	V
VHALF	VREF_CR[VHALFSEL] = 00	-	VREF/8	-	V
	VREF_CR[VHALFSEL] = 01	-	VREF/4	-	V
	VREF_CR[VHALFSEL] = 10	-	25*VREF/64	-	V
	VREF_CR[VHALFSEL] = 11	VREF/2 - 0.2	VREF/2	VREF/2 + 0.2	V

### 5.7.3 FU6864Q

Table 5-23 FU6864Q VREF and VHALF Electrical Characteristics

( $T_A = -40^{\circ}\text{C} \sim 85^{\circ}\text{C}$  and  $V_{CC} = 12\text{V} \sim 20\text{V}$ )

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VREF	VREF_CR[VREFVSEL] = 00	4.3	4.5	4.7	V
	VREF_CR[VREFVSEL] = 01	-	VDD5	-	V
	VREF_CR[VREFVSEL] = 11	-	4	-	V
	VREF_CR[VREFVSEL] = 10	-	3	-	V
VHALF	VREF_CR[VHALFSEL] = 00	-	VREF/8	-	V
	VREF_CR[VHALFSEL] = 01	-	VREF/4	-	V
	VREF_CR[VHALFSEL] = 10	-	25*VREF/64	-	V
	VREF_CR[VHALFSEL] = 11	VREF/2 - 0.2	VREF/2	VREF/2 + 0.2	V

### 5.7.4 FU6864L

Table 5-24 FU6864L VREF and VHALF Electrical Characteristics

( $T_A = -40^{\circ}\text{C} \sim 85^{\circ}\text{C}$  and  $V_{CC} = 12\text{V} \sim 20\text{V}$ )

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VREF	VREF_CR[VREFVSEL] = 00	4.3	4.5	4.7	V
	VREF_CR[VREFVSEL] = 01	-	VDD5	-	V
	VREF_CR[VREFVSEL] = 11	-	4	-	V
	VREF_CR[VREFVSEL] = 10	-	3	-	V
VHALF	VREF_CR[VHALFSEL] = 00	-	VREF/8	-	V
	VREF_CR[VHALFSEL] = 01	-	VREF/4	-	V
	VREF_CR[VHALFSEL] = 10	-	25*VREF/64	-	V
	VREF_CR[VHALFSEL] = 11	VREF/2 - 0.2	VREF/2	VREF/2 + 0.2	V

## 5.8 Operational Amplifier Electrical Characteristics

### 5.8.1 FU6815L

Table 5-25 FU6815L Operational Amplifier Electrical Characteristics

( $T_A = 25^{\circ}\text{C}$  and  $V_{CC} = 5\text{V} \sim 28\text{V}$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VICMR Common-mode Input Voltage Range		0	-	VDD5 - 1.5	V
VOS Operational Amplifier Offset Voltage	$T_A = 25^{\circ}\text{C}$	-	5	10	mV
AOL Open-loop Gain	$R_L = 100\text{k}\Omega$	-	80	-	dB
Unity-gain Bandwidth (UGBW)	$C_L = 40\text{pF}$	6	10	-	MHz
Slew Rate (SR)	$C_L = 40\text{pF}$	10	15	-	V/ $\mu\text{s}$
Operational Amplifier Gain <sup>[1]</sup>	AMP_CR1[AMP0_GAIN] = 001	1.88	2	2.12	-
	AMP_CR1[AMP0_GAIN] = 010	3.76	4	4.24	-
	AMP_CR1[AMP0_GAIN] = 011	7.5	8	8.5	-
	AMP_CR1[AMP0_GAIN] = 100	15	16	17	-



### 5.8.2 FU6865Q

Table 5-26 FU6865Q Operational Amplifier Electrical Characteristics

(T<sub>A</sub> = 25°C and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VICMR Common-mode Input Voltage Range		0	-	VDD5 - 1.5	V
VOS Operational Amplifier Offset Voltage	T <sub>A</sub> = 25°C	-	5	10	mV
AOL Open-loop Gain	R <sub>L</sub> = 100kΩ	-	80	-	dB
Unity-gain Bandwidth (UGBW)	C <sub>L</sub> = 40pF	6	10	-	MHz
Slew Rate (SR)	C <sub>L</sub> = 40pF	10	15	-	V/μs
Operational Amplifier Gain <sup>[1]</sup>	AMP_CR1[AMP0_GAIN] = 001	1.88	2	2.12	-
	AMP_CR1[AMP0_GAIN] = 010	3.76	4	4.24	-
	AMP_CR1[AMP0_GAIN] = 011	7.5	8	8.5	-
	AMP_CR1[AMP0_GAIN] = 100	15	16	17	-

### 5.8.3 FU6864Q

Table 5-27 FU6864Q Operational Amplifier Electrical Characteristics

(T<sub>A</sub> = 25°C and VCC = 12V ~ 20V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VICMR Common-mode Input Voltage Range		0	-	VDD5 - 1.5	V
VOS Operational Amplifier Offset Voltage	T <sub>A</sub> = 25°C	-	5	-	mV
AOL Open-loop Gain	R <sub>L</sub> = 100kΩ	-	80	-	dB
Unity-gain Bandwidth (UGBW)	C <sub>L</sub> = 40pF	6	10	-	MHz
Slew Rate (SR)	C <sub>L</sub> = 40pF	10	15	-	V/μs
Operational Amplifier Gain <sup>[1]</sup>	AMP_CR1[AMP0_GAIN] = 001	1.88	2	2.12	-
	AMP_CR1[AMP0_GAIN] = 010	3.76	4	4.24	-
	AMP_CR1[AMP0_GAIN] = 011	7.5	8	8.5	-
	AMP_CR1[AMP0_GAIN] = 100	15	16	17	-

### 5.8.4 FU6864L

Table 5-28 FU6864L Operational Amplifier Electrical Characteristics

(T<sub>A</sub> = 25°C and VCC = 12V ~ 20V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VICMR Common-mode Input Voltage Range		0	-	VDD5 - 1.5	V
VOS Operational Amplifier Offset Voltage	T <sub>A</sub> = 25°C	-	5	-	mV
AOL Open-loop Gain	R <sub>L</sub> = 100kΩ	-	80	-	dB
Unity-gain Bandwidth (UGBW)	C <sub>L</sub> = 40pF	6	10	-	MHz
Slew Rate (SR)	C <sub>L</sub> = 40pF	10	15	-	V/μs

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Operational Amplifier Gain <sup>[1]</sup>	AMP_CR1[AMP0_GAIN] = 001	1.88	2	2.12	-
	AMP_CR1[AMP0_GAIN] = 010	3.76	4	4.24	-
	AMP_CR1[AMP0_GAIN] = 011	7.5	8	8.5	-
	AMP_CR1[AMP0_GAIN] = 100	15	16	17	-

Note: The operational amplifier gain is measured when both positive and negative inputs of the operational amplifier are connected in series with 1K $\Omega$  resistors. The operational amplifier gain varies with external resistors.

## 5.9 BEMF Electrical Characteristics

### 5.9.1 FU6815L

Table 5-29 FU6815L BEMF Electrical Characteristics

(T<sub>A</sub> = 25°C, VCC\_MODE = 0 and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
BEMF Built-in Resistor		5.4	6.8	8.2	k $\Omega$
Relative Accuracy between BEMF Built-in Resistors		-	1	-	%

### 5.9.2 FU6865Q

Table 5-30 FU6865Q BEMF Electrical Characteristics

(T<sub>A</sub> = 25°C, VCC\_MODE = 0 and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
BEMF Built-in Resistor		5.4	6.8	8.2	k $\Omega$
Relative Accuracy between BEMF Built-in Resistors		-	1	-	%

### 5.9.3 FU6864Q

Table 5-31 FU6864Q BEMF Electrical Characteristics

(T<sub>A</sub> = 25°C and VCC = 12V ~ 20V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
BEMF Built-in Resistor		5.4	6.8	8.2	k $\Omega$
Relative Accuracy between BEMF Built-in Resistors		-	1	-	%

### 5.9.4 FU6864L

Table 5-32 FU6864L BEMF Electrical Characteristics

(T<sub>A</sub> = 25°C and VCC = 12V ~ 20V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
BEMF Built-in Resistor		5.4	6.8	8.2	k $\Omega$
Relative Accuracy between BEMF Built-in Resistors		-	1	-	%

## 5.10 OSC Electrical Characteristics

SYCLK refers to system clock rate, and T to system clock cycle. Unless otherwise specified, the system clock rate of chip is 24MHz and  $T = 1/\text{SYCLK}$ .

### 5.10.1 FU6815L

Table 5-33 FU6815L OSC Electrical Characteristics

( $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$ ,  $V_{CC\_MODE} = 0$  and  $V_{CC} = 5\text{V} \sim 28\text{V}$ )

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
System Clock Rate		23.5	24	24.5	MHz
Low-speed Clock Rate		29	32.8	37	kHz

### 5.10.2 FU6865Q

Table 5-34 FU6865Q OSC Electrical Characteristics

( $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$ ,  $V_{CC\_MODE} = 0$  and  $V_{CC} = 5\text{V} \sim 28\text{V}$ )

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
System Clock Rate		23.5	24	24.5	MHz
Low-speed Clock Rate		29	32.8	37	kHz

### 5.10.3 FU6864Q

Table 5-35 FU6864Q OSC Electrical Characteristics

( $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$  and  $V_{CC} = 12\text{V} \sim 20\text{V}$ )

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
System Clock Rate		23.5	24	24.5	MHz
Low-speed Clock Rate		29	32.8	37	kHz

### 5.10.4 FU6864L

Table 5-36 FU6864L OSC Electrical Characteristics

( $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$  and  $V_{CC} = 12\text{V} \sim 20\text{V}$ )

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
System Clock Rate		23.5	24	24.5	MHz
Low-speed Clock Rate		29	32.8	37	kHz

## 5.11 Reset Electrical Characteristics

### 5.11.1 FU6815L

Table 5-37 FU6815L Reset Electrical Characteristics

( $T_A = 25^\circ\text{C}$ ,  $VCC\_MODE = 0$  and  $VCC = 5V \sim 28V$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Minimum Time for RSTN Released to Low		50	-	-	$\mu\text{s}$
VDD5 Reset Threshold	Reset Voltage LVR = 3.0V	2.8	3.0	3.2	V

### 5.11.2 FU6865Q

Table 5-38 FU6865Q Reset Electrical Characteristics

( $T_A = 25^\circ\text{C}$ ,  $VCC\_MODE = 0$  and  $VCC = 5V \sim 28V$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Minimum Time for RSTN Released to Low		50	-	-	$\mu\text{s}$
VDD5 Reset Threshold	Reset Voltage LVR = 3.0V	2.8	3.0	3.2	V

### 5.11.3 FU6864Q

Table 5-39 FU6864Q Reset Electrical Characteristics

( $T_A = 25^\circ\text{C}$  and  $VCC = 12V \sim 20V$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Minimum Time for RSTN Released to Low		50	-	-	$\mu\text{s}$
VDD5 Reset Threshold	Reset Voltage LVR = 3.0V	2.8	3.0	3.2	V

### 5.11.4 FU6864L

Table 5-40 FU6864L Reset Electrical Characteristics5-1

( $T_A = 25^\circ\text{C}$  and  $VCC = 12V \sim 20V$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Minimum Time for RSTN Released to Low		50	-	-	$\mu\text{s}$
VDD5 Reset Threshold	Reset Voltage LVR = 3.0V	2.8	3.0	3.2	V

## 5.12 LDO Electrical Characteristics

### 5.12.1 FU6815L

Table 5-41 FU6815L LDO Electrical Characteristics

( $T_A = 25^\circ\text{C}$ ,  $VCC = 5V \sim 28V$  and  $VCC\_MODE = 0$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VDD5 Voltage	$VCC = 7V \sim 28V$ and $VCC\_MODE = 0$	4.7	5	5.3	V

### 5.12.2 FU6865Q

Table 5-42 FU6865Q LDO Electrical Characteristics

( $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 5\text{V} \sim 28\text{V}$  and  $V_{CC\_MODE} = 0$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VDD5 Voltage	$V_{CC} = 7\text{V} \sim 28\text{V}$ and $V_{CC\_MODE} = 0$	4.7	5	5.3	V

### 5.12.3 FU6864Q

Table 5-43 FU6864Q LDO Electrical Characteristics

( $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 12\text{V} \sim 20\text{V}$  and  $V_{CC\_MODE} = 0$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VDD5 Voltage	$V_{CC} = 12\text{V} \sim 20\text{V}$ and $V_{CC\_MODE} = 0$	4.7	5	5.3	V

### 5.12.4 FU6864L

Table 5-44 FU6864L LDO Electrical Characteristics

( $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 12\text{V} \sim 20\text{V}$  and  $V_{CC\_MODE} = 0$  unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VDD5 Voltage	$V_{CC} = 12\text{V} \sim 20\text{V}$ and $V_{CC\_MODE} = 0$	4.7	5	5.3	V

## 5.13 Package Thermal Resistance

### 5.13.1 FU6815L LQFP48

Table 5-45 FU6815L LQFP48 Package Thermal Resistance

Parameter	Test Conditions	Value	Unit
Junction-to-ambient Temperature Thermal Resistance $\theta_{JA}^{[1]}$	JEDEC standard, 2S2P PCB	52.4	$^\circ\text{C}/\text{W}$
	JEDEC standard, 1S0P PCB	72.2	$^\circ\text{C}/\text{W}$
Junction-to-case Temperature Thermal Resistance $\theta_{JC}^{[1]}$	JEDEC standard, 1S0P PCB	17	$^\circ\text{C}/\text{W}$

### 5.13.2 FU6865Q QFN56

Table 5-46 FU6865Q QFN56 Package Thermal Resistance

Parameter	Test Conditions	Value	Unit
Junction-to-ambient Temperature Thermal Resistance $\theta_{JA}^{[1]}$	JEDEC standard, 2S2P PCB	33	$^\circ\text{C}/\text{W}$
	JEDEC standard, 1S0P PCB	55	$^\circ\text{C}/\text{W}$
Junction-to-case Temperature Thermal Resistance $\theta_{JC}^{[1]}$	JEDEC standard, 2S2P PCB	9.2	$^\circ\text{C}/\text{W}$

**5.13.3 FU6864Q QFN48-38**

Table 5-47 QFN48-38 Package Thermal Resistance

Parameter	Test Conditions	Value	Unit
Junction-to-ambient Temperature Thermal Resistance $\theta_{JA}^{[1]}$	JEDEC standard, 2S2P PCB	27	°C/W
	JEDEC standard, 1S0P PCB	12	°C/W
Junction-to-case Temperature Thermal Resistance $\theta_{JC}^{[1]}$	JEDEC standard, 2S2P PCB	15	°C/W

**5.13.4 FU6864L LQFP52**

Table 5-48 FU6864L LQFP52 Package Thermal Resistance

Parameter	Test Conditions	Value	Unit
Junction-to-ambient Temperature Thermal Resistance $\theta_{JA}^{[1]}$	JEDEC standard, 2S2P PCB	43	°C/W
Junction-to-case Temperature Thermal Resistance $\theta_{JC}^{[1]}$	JEDEC standard, 2S2P PCB	13	°C/W

Note:

[1] The actual measurements may vary depending on the conditions.

## 6 Reset Control

### 6.1 Reset Source (RST\_SR)

The chip includes a reset circuitry with 7 reset sources:

- Power on reset (RSTPOW)
- External pin reset (RSTEXT)
- Low voltage detector reset (RSTLVD)
- Watchdog timer reset (RSTWDT)
- Flash error detector reset (RSTFED)
- Debug reset (RSTDBG)
- Soft reset (SOFTR)

The reset flag is queryable and recorded in register RST\_SR. Following the last reset, the affected reset flag is set to “1” and all other reset flags are cleared to “0”. In order to clear a reset flag, you can set RST\_SR[RSTCLR] flag to “1” so that RST\_SR[7:3]&RST\_SR[0] are cleared. After reset, MCU starts the program from address 0x0000.

### 6.2 Reset Enable

See the corresponding control registers.

### 6.3 External Reset and Power-on Reset

The chip resets when RSTN pin remains low for 50 $\mu$ s.

The chip resets when the chip powers on and the voltage settles above the reset voltage threshold.

### 6.4 Low Voltage Detector reset

The chip’s internal circuitry monitors VDD. When VDD voltage drops to a level below  $V_{RST}$ , the internal monitor circuitry sends a LVD reset signal to reset the chip.

Configuring corresponding register enables VDD monitor circuitry and sets  $V_{RST}$ .

### 6.5 Watchdog Timer Reset

After the watchdog timer (WDT) is enabled, the software periodically writes 1 to WDT\_CR[WDTRF] which initializes watchdog up timer. When watchdog up counter reaches its maximum value, WDT generates an output pulse to reset the chip, which ensures the software runs normally.

### 6.6 Flash Error Detector Reset

The Flash memory can be programmed by the software using MOVX instruction for read/write/erase operations. A Flash error detector reset (RSTFED) occurs if a Flash erase is attempted targeting the last sector

(0x7F00~0x7FFF) or a Flash write is attempted targeting the last byte (0x7FFF). RSTFED is always enabled and cannot be disabled.

## 6.7 Debug Reset

Click Reset button of IDE to send a debug reset signal when the chip enters the debug state.

## 6.8 Soft Reset

The chip resets immediately when RST\_SR[SOFTR] is set to 1. After reset, the flag RST\_SR[SOFTR] is set to 1.

## 6.9 Reset Registers

### 6.9.1 RST\_SR (0xC9)

Bit	7	6	5	4	3	2	1	0
Name	RSTPOW/ RSTCLR	RSTEXT	RSTLVD	RSV	RSTWDT	RSTFED	RSTDBG	SOFTR
Type	R/W1	R	R	-	R	R	R	R/W1
Reset	-	-	-	-	-	-	-	-
Bit	Name	Description						
[7]	RSTPOW/ RSTCLR	Power-On Reset Flag Read: 0: Last reset was not a power-on reset. 1: Last reset was a power-on reset. Write: 0: No effect. 1: RST_SR[7:3]&RST_SR[0] are cleared to "0".						
[6]	RSTEXT	External RST Pin Reset Flag 0: Last reset was not an RST pin reset. 1: Last reset was an RST pin reset.						
[5]	RSTLVD	Low Voltage Detection (LVD) Reset Flag 0: Last reset was not an LVD reset. 1: Last reset was an LVD reset.						
[4]	RSV	Reserved						
[3]	RSTWDT	WDT Reset Flag 0: Last reset was not a WDT reset. 1: Last reset was a WDT reset.						
[2]	RSTFED	Flash Error Detector Reset Flag 0: Last reset was not a Flash error detector reset. 1: Last reset was a Flash error detector reset.						
[1]	RSTDBG	Debug Reset Flag 0: Last reset was not a debug reset. 1: Last reset was a debug reset.						
[0]	SOFTR	Soft Reset Flag Read: 0: Last reset was not a soft reset. 1: Last reset was a soft reset. Write: 0: No effect. 1: A soft reset is generated.						



## 7 Interrupt

### 7.1 Interrupt Introduction

The chip includes an interrupt system with a total of 16 interrupt sources. Each interrupt source can be individually programmed in IP0 ~ IP3 registers with one of four priority levels. Interrupt flags (IF) are located in an SFRs or XSFRs. The associated IF is set by the hardware to 1 when the internal circuitry or an external source meets the interrupt conditions. If IE[EA] = 1 and both the associated interrupt EA and IF bits are set to 1, an interrupt request is generated and sent to CPU. If no other interrupt service routine (ISR) of greater priority is currently being serviced, the system enters interrupt state to service the requesting ISR.

Each interrupt source except the Reset Interrupt can be assigned a priority level. A low priority interrupt can be interrupted by a high priority interrupt. The low priority interrupt will not be serviced until the ISR for the high priority interrupt completes. An interrupt will not be preempted by another of the same priority level. Each interrupt source can be individually configured to one of four priority levels in the Interrupt Priority (IP) register. Priority level assigned ascends from 0 to 3 and is defaulted to 0. If two interrupt requests are generated at the same time, the interrupt with the higher priority is serviced first. If two interrupt sources have the same priority level, a fixed priority order is used to arbitrate. See Table 7-1 for the interrupt sources and default priority orders, where the lower the mark the higher the priority level.

### 7.2 Interrupt Enable

IE[EA] is the global interrupt enable bit. The MCU does not respond to any interrupt request when IE[EA] = 0.

Each interrupt source can be individually enabled or disabled by configuring the corresponding interrupt enable bit in an SFR or XSFR. When the enable bit of the global interrupt or an interrupt is cleared, the interrupt flag that is set to 1 is held in a pending state. Once the enable bit is set to 1, the MCU immediately enters the interrupt subroutine. Therefore, make sure to clear corresponding interrupt flag bit before enabling the interrupt.

### 7.3 External Interrupts

The external interrupt has 2 interrupt sources: INT0 and INT1. They both can be configured as interrupt on rising edge, interrupt on falling edge or interrupt on edge changes (rise or fall).

The digital input signals from P0.0~P0.3, P1.1, P0.5~P0.6 and output signals from CMP4 can be used to trigger an INT0. The interrupt source is selected through LVSR[EXT0CFG] bit. These trigger sources share one interrupt entry point, one interrupt flag bit TCON[IF0] and one interrupt enable bit IE[EX0]. TCON[IT0] bit selects the interrupt edge. IP0[PX0] bit configures the priority level.

The digital input signals from P1.0~P1.7, P4.0~P4.6 and P0.4 can be used to trigger an INT1. P1\_IF and P4\_IF are interrupt flag bits, and P1\_IE and P4\_IE are interrupt enable bits. Each trigger source has a

corresponding interrupt flag bit and an interrupt enable bit. INT1 can select multiple trigger sources that are recognized by P1\_IF and P4\_IF in the interrupt subroutine. These 16 interrupt sources share one interrupt entry and one interrupt enable bit IE[EX1]. To enable INT1, first set IE[EX1] to “1” and then configure the corresponding enable bit. The interrupt edge is configured by TCON[IT1] bit, and the priority level by IP0[PX1] bit. See 7.5.7 P1\_IE (0xD1) ~ 7.5.10 P4\_IF (0xD4) for INT1 interrupt flags and enable registers.

## 7.4 Interrupt Summary

Table 7-1 Interrupt Summary

Interrupt Source	Priority Order	Interrupt Vector	Interrupt Flag	Cleared by Software?	Enable Bit	Priority Control
Reset	Highest	0x0000	None	N	Always enabled	Highest
LVW Interrupt TSD Interrupt	0	0x0003	LVSR[0] TCON[5]	Y	CCFG1[6] IE[1]	IP0[1:0]
INT0	1	0x000B	TCON[2]	Y	IE[0]	IP0[3:2]
INT1	2	0x0013	P1_IF[7:0] P4_IF[7:0]	Y	IE[2]	IP0[5:4]
FG Interrupt DRV Compare Match Interrupt	3	0x001B	DRV_SR[5:4]	Y	DRV_SR[3] DRV_SR[2:0]	IP0[7:6]
Timer2 Interrupt	4	0x0023	TIM2_CR1[7:5]	Y	TIM2_CR1[4:3] TIM2_CR0[3]	IP1[1:0]
Timer1 Interrupt	5	0x002B	TIM1_SR[5:0]	Y	TIM1_IER[5:0]	IP1[3:2]
ADC Interrupt	6	0x0033	ADC_CR[0]	Y	ADC_CR[1]	IP1[5:4]
CMP0/1/2 Interrupt Hall Interrupt	7	0x003B	CMP_SR[6:4] HALL_CR[7]	Y	CMP_CR0[5:0] HALL_CR[6]	IP1[7:6]
RTC Interrupt	8	0x0043	RTC_STA[6]	Y	IE[6]	IP2[1:0]
Timer3 Interrupt	9	0x004B	TIM3_CR1[7:5]	Y	TIM3_CR1[4:3] TIM3_CR0[3]	IP2[3:2]
Systick Interrupt	10	0x0053	DRV_SR[7]	Y	DRV_SR[6]	IP2[5:4]
Timer4 Interrupt	11	0x005B	TIM4_CR1[7:5]	Y	TIM4_CR1[4:3] TIM4_CR0[3]	IP2[7:6]
CMP3 Interrupt	12	0x0063	CMP_SR[7]	Y	CMP_CR0[7:6]	IP3[1:0]
I2C Interrupt UART1 Interrupt	13	0x006B	I2C_SR[0] UT_CR[1:0]	Y	I2C_CR[0] IE[4]	IP3[3:2]
SPI Interrupt UART2 Interrupt	14	0x0073	SPI_CR1[7:4] UT2_CR[1:0]	Y	IE[3] UT2_BAUDH[5]	IP3[5:4]
DMA Interrupt	15	0x007B	DMA0_CR0[0] DMA1_CR0[0]	Y	DMA0_CR0[2]	IP3[7:6]

Notes:

- UT\_CR[RI], UT\_CR[TI], UT2\_CR[UT2RI], UT2\_CR[UT2TI], DMA0\_CR0[DMAIF] and DMA1\_CR0[DMAIF] flags can be cleared to “0” or set to “1” by software; when these flags are set to “1”, an interrupt request is generated. Other interrupt flags can only be cleared to “0” by software, and setting them to “1” has no meaning.
- For a register containing multiple interrupt flags, you can write a “1” to active interrupt flags in order to prevent clearing a interrupt flag to “0”. Take DRV\_SR as an example. When DRV\_SR[SYSTIF] is cleared to “0” by software, you can use the statement `DRV_SR = (DRV_SR&0x7F) | 0x30` to prevent the software from clearing DRV\_SR[FGIF] and DRV\_SR[DCIF] to “0”.

## 7.5 Interrupt Registers

### 7.5.1 IE (0xA8)

Bit	7	6	5	4	3	2	1	0
Name	EA	RTCIE	RSV	ES0	SPIIE	EX1	TSDIE	EX0
Type	R/W	R/W	-	R/W	R/W	R/W	R/W	R/W
Reset	0	0	-	0	0	0	0	0
Bit	Name	Description						
[7]	EA	Enable All Interrupts 0: Disable 1: Enable						
[6]	RTCIE	RTC Interrupt Enable 0: Disable 1: Enable						
[5]	RSV	Reserved						
[4]	ES0	UART1 Interrupt Enable 0: Disable 1: Enable						
[3]	SPIIE	SPI Interrupt Enable 0: Disable 1: Enable						
[2]	EX1	External Interrupt 1 (INT1) Enable 0: Disable 1: Enable						
[1]	TSDIE	TSD Interrupt Enable 0: Disable 1: Enable						
[0]	EX0	External Interrupt 0 (INT0) Enable 0: Disable 1: Enable						

### 7.5.2 IP0 (0x8A)

Bit	7	6	5	4	3	2	1	0
Name	PDRV		PX1		PX0		PLVW_TSD	
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:6]	PDRV	FG/DRV Compare Match Interrupt Priority Setting						
[5:4]	PX1	External Interrupt 1 (INT1) Priority Setting						
[3:2]	PX0	External Interrupt 0 (INT0) Priority Setting						
[1:0]	PLVW_TSD	LVW/TSD Interrupt Priority Setting						

Note: Priority level assigned ascends from 0 to 3, totaling 4 levels.

**7.5.3 IP1 (0x8B)**

Bit	7	6	5	4	3	2	1	0
Name	PCMP		PADC		PTIM1		PTIM2	
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:6]	PCMP	CMP0/1/2 Interrupt Priority Setting						
[5:4]	PADC	ADC Interrupt Priority Setting						
[3:2]	PTIM1	Timer1 Interrupt Priority Setting						
[1:0]	PTIM2	Timer2 Interrupt Priority Setting						

Note: Priority level assigned ascends from 0 to 3, totaling 4 levels.

**7.5.4 IP2 (0x8C)**

Bit	7	6	5	4	3	2	1	0
Name	PTIM4		PSYSTICK		PTIM3		PRTC	
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:6]	PTIM4	Timer4 Interrupt Priority Setting						
[5:4]	PSYSTICK	Systick Interrupt Priority Setting						
[3:2]	PTIM3	Timer3 Interrupt Priority Setting						
[1:0]	PRTC	RTC Interrupt Priority Setting						

Note: Priority level assigned ascends from 0 to 3, totaling 4 levels.

**7.5.5 IP3 (0x8D)**

Bit	7	6	5	4	3	2	1	0
Name	PDMA		PSPI_UT2		PI2C_UT1		PCMP3	
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:6]	PDMA	DMA Interrupt Priority Setting						
[5:4]	PSPI_UT2	SPI/UART2 Interrupt Priority Setting						
[3:2]	PI2C_UT1	I <sup>2</sup> C/UART1 Interrupt Priority Setting						
[1:0]	PCMP3	CMP3 Interrupt Priority Setting						

Note: Priority level assigned ascends from 0 to 3, totaling 4 levels.

**7.5.6 TCON (0x88)**

Bit	7	6	5	4	3	2	1	0
Name	RSV		TSDIF	IT1		IF0	IT0	
Type	-	-	R/W0	R/W	R/W	R/W0	R/W	R/W
Reset	-	-	0	0	0	0	0	0
Bit	Name	Description						
[7:6]	RSV	Reserved						

[5]	TSDIF	<p>TSD Interrupt Flag This bit is set by hardware to “1” when an over-temperature event occurs. Read: 0: No interrupt pending 1: Interrupt pending Write: 0: This bit is cleared to “0” 1: No effect</p> <p>Note: This flag is often used with the overtemperature status bit LVSR[TSDIF].</p>
[4:3]	IT1	<p>External Interrupt 1 (INT1) Edge Select 00: Interrupt on rising edge 01: Interrupt on falling edge 1X: Interrupt on edge changes (rise or fall)</p>
[2]	IF0	<p>External Interrupt 0 (INT0) Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect</p>
[1:0]	IT0	<p>External Interrupt 0 (INT0) Edge Select 00: Interrupt on rising edge 01: Interrupt on falling edge 1X: Interrupt on edge changes (rise or fall)</p>

### 7.5.7 P1\_IE (0xD1)

Bit	7	6	5	4	3	2	1	0
Name	P17_IE	P16_IE	P15_IE	P14_IE	P13_IE	P12_IE	P11_IE	P10_IE
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	P17_IE	P1.7 INT1 Enable 0: Disable 1: Enable						
[6]	P16_IE	P1.6 INT1 Enable 0: Disable 1: Enable						
[5]	P15_IE	P1.5 INT1 Enable 0: Disable 1: Enable						
[4]	P14_IE	P1.4 INT1 Enable 0: Disable 1: Enable						
[3]	P13_IE	P1.3 INT1 Enable 0: Disable 1: Enable						
[2]	P12_IE	P1.2 INT1 Enable 0: Disable 1: Enable						
[1]	P11_IE	P1.1 INT1 Enable 0: Disable 1: Enable						
[0]	P10_IE	P1.0 INT1 Enable 0: Disable 1: Enable						

**7.5.8 P1\_IF (0xD2)**

Bit	7	6	5	4	3	2	1	0
Name	P17_IF	P16_IF	P15_IF	P14_IF	P13_IF	P12_IF	P11_IF	P10_IF
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	P17_IF	P1.7 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending						
[6]	P16_IF	P1.6 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending						
[5]	P15_IF	P1.5 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending						
[4]	P14_IF	P1.4 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending						
[3]	P13_IF	P1.3 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending						
[2]	P12_IF	P1.2 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending						
[1]	P11_IF	P1.1 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending						
[0]	P10_IF	P1.0 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending						

**7.5.9 P4\_IE (0xD3)**

Bit	7	6	5	4	3	2	1	0
Name	P04_IE	P46_IE	P45_IE	P44_IE	P36_IE	P42_IE	P41_IE	P07_IE
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	P04_IE	P0.4 INT1 Enable 0: Disable 1: Enable						
[6]	P46_IE	P4.6 INT1 Enable 0: Disable 1: Enable						
[5]	P45_IE	P4.5 INT1 Enable 0: Disable 1: Enable						
[4]	P44_IE	P4.4 INT1 Enable 0: Disable 1: Enable						
[3]	P36_IE	P3.6 INT1 Enable 0: Disable 1: Enable						

[2]	P42_IE	P4.2 INT1 Enable 0: Disable 1: Enable
[1]	P41_IE	P4.1 INT1 Enable 0: Disable 1: Enable
[0]	P07_IE	P0.7 INT1 Enable 0: Disable 1: Enable

**7.5.10 P4\_IF (0xD4)**

Bit	7	6	5	4	3	2	1	0
Name	P04_IF	P46_IF	P45_IF	P44_IF	P36_IF	P42_IF	P41_IF	P07_IF
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[7]	P04_IF	P0.4 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending
[6]	P46_IF	P4.6 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending
[5]	P45_IF	P4.5 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending
[4]	P44_IF	P4.4 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending
[3]	P36_IF	P3.6 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending
[2]	P42_IF	P4.2 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending
[1]	P41_IF	P4.1 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending
[0]	P07_IF	P0.7 INT1 Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending

## 8 I<sup>2</sup>C

### 8.1 I<sup>2</sup>C Introduction

The I<sup>2</sup>C module provides an industry standard two-wire serial interface and is a simple bi-directional synchronous serial bus for communication between MCU and external I<sup>2</sup>C devices, as shown in Figure 8-1. The bus consists of two serial lines: SDA (serial data line) and SCL (serial clock line). P0.0 serves as SDA port and P0.1 as SCL port. After I<sup>2</sup>C is enabled, P0.0 and P0.1 automatically shifts into open-drain outputs.

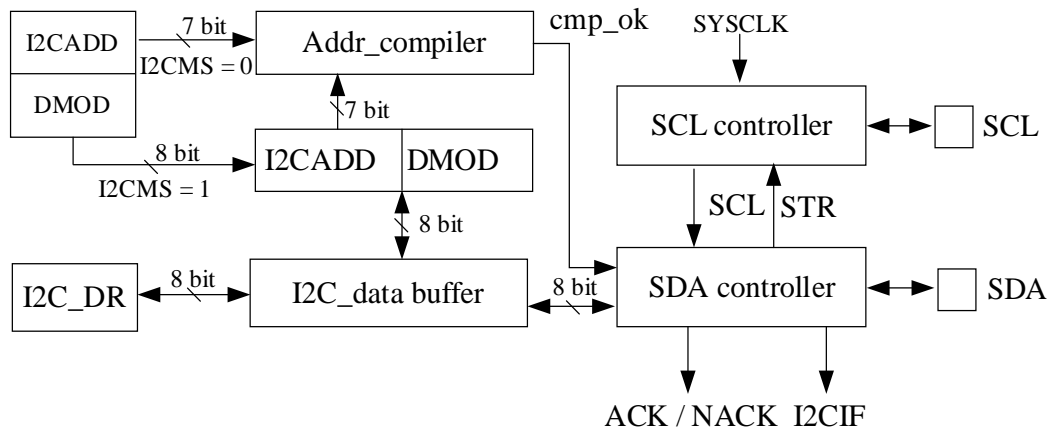


Figure 8-1 I<sup>2</sup>C Block Diagram

#### Features:

- Supports standard mode (up to 100kHz), fast mode (up to 400kHz) and fast plus mode (up to 1MHz)
- Supports master mode and slave mode
- Supports 7-bit address mode and general call address mode
- Supports DMA data transfer

Both SDA and SCL lines are high level when the bus is idle, which is the only basis for detecting whether the bus is idle or not. Only one master device and at least one slave device are active on the bus during the transmission. When the bus is occupied, other devices must wait for the bus idle to start an I<sup>2</sup>C communication. The master starts the bus to transfer data. Clock signal is sent to all devices via SCL and the slave address and read/write mode are sent via SDA. When a device on the bus matches the address, it acts as a slave. The relationships between masters and slaves or data transfer direction on the bus are not constant. The process for the master to send data to the slave is shown in Figure 8-2. The master first addresses the slave device and waits for the slave response. And then, it sends data to the slave. Finally, the master terminates the data transmission. The process for the master to receive data from the slave is shown in Figure 8-3. The master first addresses the slave and waits for the slave response. And then, it receives the data from the slave. Finally, the master terminates the data transmission. In this case, the master generates the timing clock and stops the data transmission.



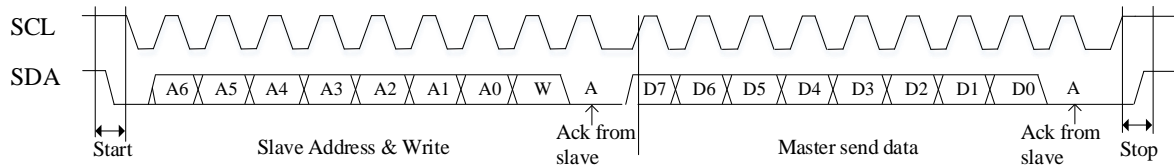


Figure 8-2 Master Transmits Data to Slave

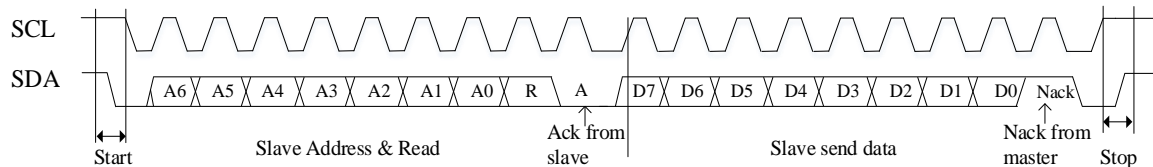


Figure 8-3 Master Receives Data from Slave

## 8.2 I<sup>2</sup>C Operations

### 8.2.1 Master Mode

1. Set I2C\_CR[I2CMS] to “1” to select master mode;
2. Configure I2C\_CR [I2CSPD] to set the clock rate of SCL;
3. Configure I2C\_ID[I2CADD] to set the slave address;
4. Configure I2C\_SR[DMOD] to set the read/write direction;
5. Set I2C\_CR[I2CEN] to “1” to enable I<sup>2</sup>C;
6. Set I2C\_SR[I2CSTA] to “1” to transmit START and address. After ACK/NACK is received, I2C\_SR[STR] is set to “1” by hardware and SCL is pulled LOW by the master;
7. Sending Data: Write the data to I2C\_DR register. The master starts to transmit data when I2C\_SR[STR] is reset and SCL is released. After the data is transmitted and ACK/NACK is received, I2C\_SR[STR] is set to “1” by hardware and SCL is pulled LOW by the master;
8. Receiving Data: The master starts to receive data when I2C\_SR[STR] is reset and SCL is released. After the data is received, I2C\_SR[STR] is set to “1” by hardware and SCL is pulled LOW by the master. Configure ACK/NACK via I2C\_SR[NACK], and then clear I2C\_SR[STR] to release SCL to transmit ACK/NACK signal. After the data is received, I2C\_SR[STR] is set to “1” by hardware and SCL is pulled LOW by the master;
9. Stop Communication: Set I2C\_SR[I2CSTP] to “1” when I2C\_SR[STR] is “1” and stop signal is sent after I2C\_SR[STR] is cleared.

### 8.2.2 Slave Mode

1. Set I2C\_CR[I2CMS] to “0” to select slave mode;
2. Configure I2C\_ID[I2CADD] to set the slave address or set I2C\_ID[GC] to “1” to enable general call mode;

3. Set I2C\_CR[I2CEN] to “1” to enable I<sup>2</sup>C;
4. After START signal and the correct address are received, I2C\_SR[I2CSTA] and I2C\_SR[STR] are set to “1” by hardware and SCL is pulled LOW by the slave. ACK/NACK is configured via I2C\_SR[NACK] and the slave determines whether to receive or send the data via I2C\_SR[DMOD];
5. Sending Data: Write the data to I2C\_DR register, and clear I2C\_SR[STR] to release SCL. The data is sent after ACK/NACK is transmitted. After the data is sent and ACK/NACK is received from the master, I2C\_SR[STR] is set to “1” by hardware and SCL is pulled LOW by the slave;
6. Receiving Data: Clear I2C\_SR[STR] to release SCL to receive data. After the data is received, I2C\_SR[STR] is set to “1” by hardware and SCL is pulled LOW by the slave. ACK/NACK is configured via I2C\_SR[NACK] to reset I2C\_SR[STR] to release SCL for ACK/NACK transmission. If new data is received, I2C\_SR[STR] is set to “1” by hardware and SCL is pulled LOW by the slave;
7. RESTART: If the slave is processing a service when receiving START signal, it stops the current routine and waits for receiving address.

### 8.2.3 I<sup>2</sup>C Interrupt Sources

The interrupt sources of I<sup>2</sup>C include:

- I2C\_SR[STR] = 1 generates an interrupt. This interrupt source is valid in both master and slave modes.
- I2C\_SR[I2CSTP] = 1 generates an interrupt. This interrupt source is only valid in slave mode.

## 8.3 I<sup>2</sup>C Registers

### 8.3.1 I2C\_CR (0x4028)

Bit	7	6	5	4	3	2	1	0
Name	I2CEN	I2CMS	RSV			I2CSPD		I2CIE
Type	R/W	R/W	-	-	-	R/W	R/W	R/W
Reset	0	0	-	-	-	0	0	0
Bit	Name	Description						
[7]	I2CEN	I <sup>2</sup> C Enable Enable the associated GPIO and switch to I <sup>2</sup> C mode, serving as collector open-drain output. The pull-up setting decides whether to pull I <sup>2</sup> C HIGH. 0: Disable 1: Enable						
[6]	I2CMS	Master/Slave Mode Selection 0: Slave 1: Master						
[5:3]	RSV	Reserved						
[2:1]	I2CSPD	I <sup>2</sup> C transfer rate setting, valid only in Master Mode 00: 100kHz 01: 400kHz 10: 1MHz 11: Reserved						

[0]	I2CIE	I <sup>2</sup> C Interrupt Enable 0: Disable 1: Enable
-----	-------	--

### 8.3.2 I2C\_ID (0x4029)

Bit	7	6	5	4	3	2	1	0
Name	I2CADD							GC
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	1	0	1	0	1	0	1	0
Bit	Name	Description						
[7:1]	I2CADD	Slave address						
[0]	GC	General call, valid only in Slave Mode 0: General call is disabled 1: General call is enabled namely, i.e., the receiving device also reads an ACK at address 0x00.						

### 8.3.3 I2C\_DR (0x402A)

Bit	7	6	5	4	3	2	1	0
Name	I2C_DR							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	I2C_DR	I <sup>2</sup> C Data Register Read: Data to be sent or received Write: Data to be sent						

### 8.3.4 I2C\_SR (0x402B)

Bit	7	6	5	4	3	2	1	0
Name	I2CBSY	DMOD	RSV	I2CSTA	I2CSTP	STR	NACK	I2CIF
Type	R	R/W	-	R/W	R/W	R/W0	R/W	R
Reset	0	0	-	0	0	0	0	0
Bit	Name	Description						
[7]	I2CBSY	I <sup>2</sup> C Busy Flag When I2C_CR[I2CEN] = 0, I2C_SR[I2CBSY] is cleared to “0” by hardware. Master Mode: After START is transmitted, I2C_SR[I2CBSY] is set to “1” by hardware; after STOP is transmitted, I2C_SR[I2CBSY] is cleared to “0” by hardware. Slave Mode: After START is received and address matches, I2C_SR[I2CBSY] is set to “1” by hardware; after STOP is received, I2C_SR[I2CBSY] is cleared to “0” by hardware.						
[6]	DMOD	I <sup>2</sup> C R/W Flag 0: WRITE (master transmits the data, and slave receives the data) 1: READ (master receives the data, and slave transmits the data) Note: Read only in Slave Mode						
[5]	RSV	Reserved						

[4]	I2CSTA	<p><b>Master Mode:</b> When this bit is configured with “1”, START and address bytes are transmitted after both SCL and SDA are HIGH confirmed by the hardware. This bit is cleared to “0” by hardware automatically when the transmission is completed, and I2C_SR[I2CSTA] writing is forbidden during data transmission. After the data is sent or received, I2C_SR[I2CSTA] is set to “1” to transmit RESTART. 0: Not START and address bytes 1: Transmit START or RESTART and address bytes</p> <p><b>Slave Mode:</b> This bit is set to “1” after hardware receives START and address matches, and cleared to “0” by software.</p> <p>Table 8-1 Mapping of I2C_SR[I2CSTA] and I2C_SR[I2CSTP] in Slave Mode</p> <table border="1" data-bbox="470 629 1374 790"> <thead> <tr> <th>I2CSTA</th> <th>I2CSTP</th> <th>I<sup>2</sup>C Data Type</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>0</td> <td>Data byte</td> </tr> <tr> <td>0</td> <td>1</td> <td>STOP</td> </tr> <tr> <td>1</td> <td>0</td> <td>START + address bytes</td> </tr> <tr> <td>1</td> <td>1</td> <td>STOP received first, then START + address bytes</td> </tr> </tbody> </table> <p>Note: When I2C_CR[I2CEN] = 0, I2C_SR[I2CSTA] is automatically cleared to “0”.</p>	I2CSTA	I2CSTP	I <sup>2</sup> C Data Type	0	0	Data byte	0	1	STOP	1	0	START + address bytes	1	1	STOP received first, then START + address bytes
I2CSTA	I2CSTP	I <sup>2</sup> C Data Type															
0	0	Data byte															
0	1	STOP															
1	0	START + address bytes															
1	1	STOP received first, then START + address bytes															
[3]	I2CSTP	<p><b>Master Mode:</b> This bit cannot be written to “1” by software unless I2C_SR[I2CBSY] = 1; STOP is transmitted after I2C_SR[STR] is cleared to release SCL. After the transmission, this bit is cleared to “0” automatically by hardware. If I2C_SR[I2CSTA] and I2C_SR[I2CSTP] are written to “1” at the same time and I2C_SR[I2CBSY] is “1”, I<sup>2</sup>C first sends STOP, then START and address bytes. After START and address bytes are transmitted, I2C_SR[STR] is set to “1” by hardware. I2C_SR[I2CSTP] writing is forbidden during data transmission. 0: STOP is not transmitted. 1: STOP is transmitted.</p> <p><b>Slave Mode:</b> This bit is set to “1” by hardware after STOP is received, and cleared to “0” by software. See Table 8-1 for status flags.</p> <p>Note: When I2C_CR[I2CEN] = 0, I2C_SR[I2CSTP] is automatically cleared to “0” by hardware.</p>															
[2]	STR	<p><b>I<sup>2</sup>C Bus Pending Flag</b></p> <p><b>Master Mode:</b> After START and address or DATA byte are transmitted, I2C_SR[STR] are set to “1” by hardware and SCL is pulled LOW. SCL is released after I2C_SR[STR] is cleared by software. When I2C_SR[I2CSTA] and I2C_SR[I2CSTP] are both “1”, I2C_SR[STR] is set to “1” only after hardware sends STOP and START &amp; address bytes.</p> <p><b>Slave Mode:</b> When DATA byte is received or START is received and address matches, I2C_SR[STR] is set to “1” by hardware and SCL is pulled LOW. SCL is released after I2C_SR[STR] is cleared by software.</p> <p>Note: The bit is set to “1” by hardware and cleared to “0” by software. When I2C_CR[I2CEN] = 0, I2C_SR[STR] is automatically cleared to “0”.</p>															
[1]	NACK	<p>This bit refers to the feedback from a receiver to a sender after a byte is transferred via I<sup>2</sup>C. It is automatically cleared to “0” when I2C_SR[I2CEN] = 0. 0: ACK, indicating that the receiver can continue to receive data. 1: NACK, indicating that the receiver attempts to stop data transmission. When the device is in READ mode, I2C_SR[NACK] is configured to transmit ACK/NACK after the 8<sup>th</sup> bit of data is received.</p>															

		0: Bit9 transmits ACK 1: Bit9 transmits NACK When the device is in WRITE mode, I2C_SR[NACK] is read to receive ACK/NACK after the 8 <sup>th</sup> bit of data is transmitted. 0: Bit9 receives ACK 1: Bit9 receives NACK
[0]	I2CIF	I <sup>2</sup> C Interrupt Flag 0: No Interrupt Pending 1: Interrupt Pending When I2C_SR[STR] = 1, an interrupt is generated in both Master and Slave modes. When I2C_SR[I2CSTP] = 1, an interrupt is generated only in Slave mode.

## 9 SPI (FU6815L/FU6865Q)

### 9.1 SPI Introduction

SPI provides access to a high-speed and full-duplex synchronous serial bus, with its block diagram shown in Figure 9-1. SPI can operate as a master or slave device in 3-wire or 4-wire mode, and supports multiple masters and slaves on a single SPI bus.

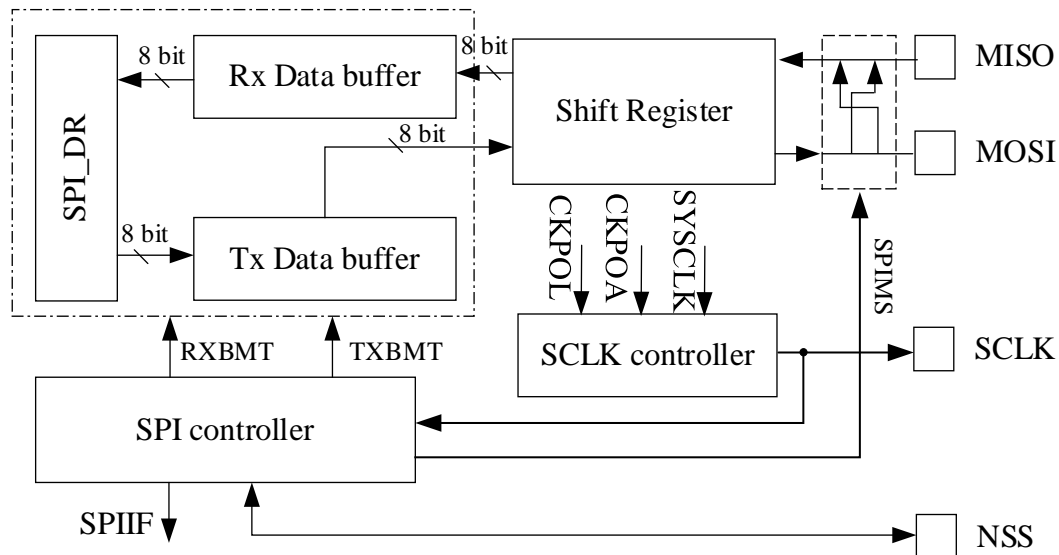


Figure 9-1 SPI Block Diagram

### 9.2 SPI Operations

#### 9.2.1 Signal Descriptions

The four signals for SPI are MOSI, MISO, SCLK and NSS.

##### 9.2.1.1 Master Output, Slave Input (MOSI)

The master-out, slave-in (MOSI) signal is an output from a master device and an input to slave devices. It is used to serially transfer data from the master to the slave. Data is transferred with most-significant bit (MSB) first, namely, the master begins its transmission by driving the MSB of the shift register on its MOSI pin.

##### 9.2.1.2 Master Input, Slave Output (MISO)

The MISO signal is an output from a slave device and an input to the master device. The MISO pin is placed in a high-impedance state when the SPI module is disabled or when the SPI operates in 4-wire mode as a slave that is not selected. When the SPI acts as a slave in 3-wire mode or operates in 4-wire mode as a slave that is selected, MISO is used to serially transfer data from the slave to the master. Data is transferred with most-significant bit (MSB) first, namely, the master begins its transmission by driving the MSB of the shift register on its MOSI pin.

### 9.2.1.3 Serial Clock (SCLK)

The serial clock (SCLK) signal is an output from the master device and an input to slave devices. It is used to synchronize serial data transmission between the master and slave. SCLK signal is generated by SPI operating as a master. In 4-wire slave mode, SCLK is ignored when the slave device is not selected (NSS=1).

### 9.2.1.4 Slave Select (NSS)

The slave-select (NSS) is dependent on the setting of SPI\_CR1[NSSMOD] bit. SPI may operate in 3-Wire Mode, 4-Wire Slave/Multi-Master Mode or 4-Wire Single Master Mode. When SPI operates in 4-Wire Slave/Multi-Master Mode, NSS is enabled as an input. In this mode, a particular SPI master function is disabled to prevent SPI bus collision where two or more masters simultaneously initiate data transfer. When SPI operates in 4-Wire Single Master Mode, the master NSS is configured as chip select output. When SPI operates in 3-Wire Mode, NSS is disabled. When SPI operates as a master, multiple addressed slave devices can be selected using general-purpose I/O pins.

When SPI\_CR1[NSSMOD] = 00, SPI operates in 3-Wire Mode. NSS port is not necessary in this mode and there is only one master and one slave on the SPI bus. The connection diagram is shown in Figure 9-2.

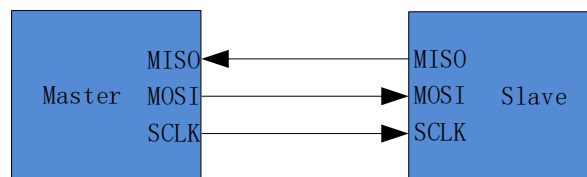


Figure 9-2 Connection Diagram of 3-Wire SPI Mode

When SPI\_CR1[NSSMOD] = 01, SPI operates in 4-Wire Slave/Multi-Master Mode. In this mode, NSS pins on the SPI bus are configured as inputs, waiting to be addressed by the master. When SPI\_CR0[SPIMS] = 0, SPI operates in 4-Wire Slave Mode. If NSS is set to “0”, the slave is selected; while NSS is set to “1”, the slave is not selected. When SPI\_CR0[SPIMS] = 1, SPI operates in Master Mode and defaults to Multi-Master Mode. When SPI operates in Multi-Master Mode, NSS is configured as an input to disable the master SPI. When NSS pin of a master on the SPI bus is pulled low, SPI\_CR0[SPIMS] and SPI\_CR1[SPIEN] are cleared to “0” by hardware to disable the SPI, and the Mode Fault Flag SPI\_CR1[MODF] is set to “1”. In this case, SPI communication remains halted before the SPI is re-enabled by software. In this mode, multiple masters are allowed for communication on the SPI bus. The connection diagram is shown in Figure 9-3.

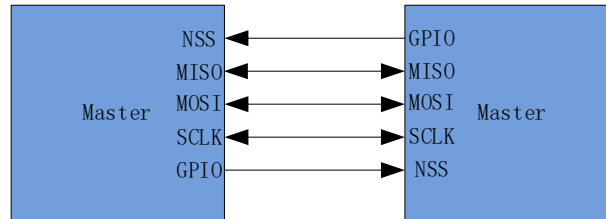


Figure 9-3 Connection Diagram of 4-Wire Multi-Master Mode

When  $SPI\_CR1[NSSMOD] = 1X$ , SPI operates in 4-Wire Single Master Mode. In this mode, NSS pin of the master on the bus is configured as an output, and NSS pin of the slave devices are configured as inputs.  $SPI\_CR1[NSSMOD0]$  setting decides the output level of NSS pin serving as signal to select a slave. Other slaves can be selected using GPIO pins. The connection diagram is shown in Figure 9-4.

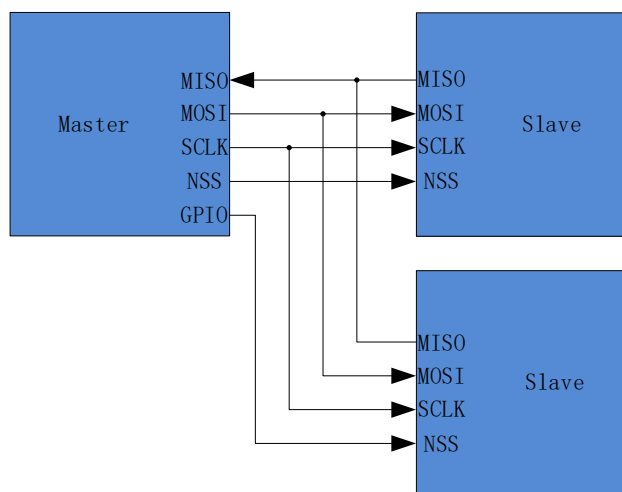


Figure 9-4 Connection Diagram of 4-Wire Single Master Mode

### 9.2.2 SPI Master Mode

When  $SPI\_CR0[SPIMS] = 1$ , SPI operates in master mode, which provides SCLK signal for SPI bus. When the data is written to  $SPI\_DR$ , it is firstly written to the transmit buffer and  $SPI\_CR1[TXBMT]$  is cleared to “0”. If the shift register is empty, the data in the transmit buffer will be transferred to the shift register for the transmission. The master SPI begins its transmission by driving the MSB of shift register on its MOSI pin. After the transmission is completed,  $SPI\_CR1[SPIIF]$  and  $SPI\_CR1[TXBMT]$  are set to “1”. While the SPI master transfers data to a slave on the MOSI line, the addressed SPI slave simultaneously transfers data in the shift register to the SPI master on the MISO line in a full-duplex operation. Therefore,  $SPI\_CR1[SPIIF]$  flag serves as both a transmit-complete flag and a receive-data-ready flag, and the data in the shift register is that received by MISO, which is transferred to the receive buffer. The data from  $SPI\_DR$  is that of the receive buffer. If the data is written to  $SPI\_DR$  when  $SPI\_CR1[TXBMT]$  is “0”, the write conflict flag bit  $SPI\_CR1[WCOL]$  will be set to “1” and the data in the transmit buffer keeps unchanged.



### 9.2.2.1 Master Mode Configuration

1. Configure SPI\_CR1[NSSMOD] to set the SPI operating mode;
2. Configure SPI\_CR0[CPOL] to set the clock polarity;
3. Configure SPI\_CR0[CPHA] to set the clock phase;
4. Set SPI\_CR0[SPIMS] to “1” to select master mode;
5. Configure SPI\_CLK to set the SCLK rate;
6. Set SPI\_CR1[SPIEN] to “1” to enable SPI;
7. Write the data to SPI\_DR. SPI transmits data for each write;
8. After SPI\_CR1[SPIIF] is set to “1”, SPI\_DR is read to receive the data.

### 9.2.3 SPI Slave Mode

When SPI\_CR0[SPIMS] = 0, SPI operates in slave mode. In this mode, SCLK signal is sent by the master SPI. The data is shifted from MOSI pin and shifted out from MISO pin. If no SCLK signal is input, shift register of the slave is in the stop state. If the signal of SCLK is input, the shift register of slave starts to receive and transmit data through MOSI and MISO pins. The slave device cannot initiate transfers. The data sent to the master device is pre-loaded into the shift register by writing to SPI\_DR. If the shift register is empty, the data in the transit buffer is transferred into the shift register. After the transmission is completed, SPI\_CR1[SPIIF] and SPI\_CR1[TXBMT] are set to “1”. The received data that is transferred into receive buffer and receive buffer empty flag bit SPI\_CR0[RXBMT] is cleared, indicating the new data has not been read. If SPI\_CR0[RXBMT] is “0” and there is new data ready to be sent to the receive buffer, SPI\_CR1[RXOVRN] is set to “1” and the data in the receive buffer remains unaffected. When data is written to SPI\_DR, SPI\_CR1[TXBMT] is cleared. If data is written in this case, the write conflict flag bit SPI\_CR1[WCOL] is set to “1” and the data in the transmit buffer keeps unchanged.

#### 9.2.3.1 Slave Mode Configuration

1. Configure SPI\_CR1[NSSMOD] to set the SPI operating mode;
2. Configure SPI\_CR0[CPOL] to set the clock polarity;
3. Configure SPI\_CR0[CPHA] to set the clock phase;
4. Set SPI\_CR0[SPIMS] to “0” to select slave mode;
5. Set SPI\_CR1[SPIEN] to 1 to enable SPI;
6. Write data to SPI\_DR and wait for the master to transmit the clock signal.

### 9.2.4 SPI Interrupt Sources

The interrupt sources of SPI include:

- SPI interrupt flag SPI\_CR1[SPIIF] is set to “1” each time after the byte is transferred.
- If SPI\_DR is written when the data in transmit buffer has not been transferred to the shift register,

the write conflict flag SPI\_CR1[WCOL] is set to “1” and the write operation will not be implemented.

- When SPI works as a master in a multi-master system and NSS pin is pulled LOW, the mode error flag SPI\_CR1[MODF] is set to “1”. When a mode error occurs, SPI\_CR0[SPIMS] and SPI\_CR1[SPIEN] are cleared. SPI is forbidden to allow another master to control the bus.
- The receive overflow flag SPI\_CR1[RXOVRN] is set to “1” when SPI operates in slave mode and a transmission is completed while the receive buffer still holds unread data from a previous transfer. And the received data will not be transferred to the receive buffer.

### 9.2.5 Serial Clock Timing

Four combinations of serial clock phase and idle polarity can be selected using the CPHA and CPOL bits in the SPI\_CR0 Register. SPI\_CR0[CPHA] selects the clock phase (the edge of the SCLK signal used to latch the data in shift register). SPI\_CR0[CPOL] selects the polarity. Both master and slave devices must be configured with the same clock phase and polarity. When the clock phase and polarity is configured, SPI shall be disabled (SPI\_CR1[SPIEN] = 0). The timing relationships of SCL and SDA in clock phase and polarity combinations are shown in Figure 9-5 and Figure 9-6.

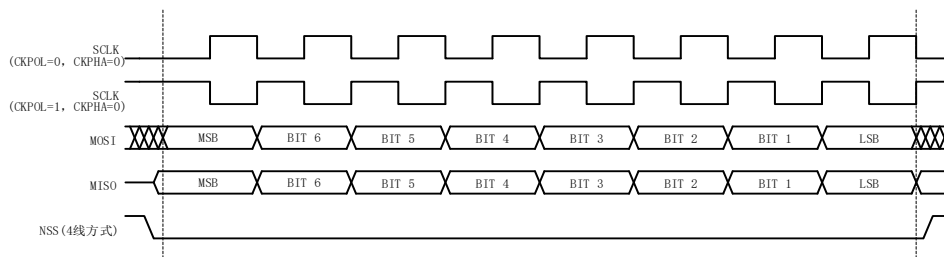


Figure 9-5 SDA/SCL Line Timing Diagram (SPI\_CR0[CPHA] = 0)

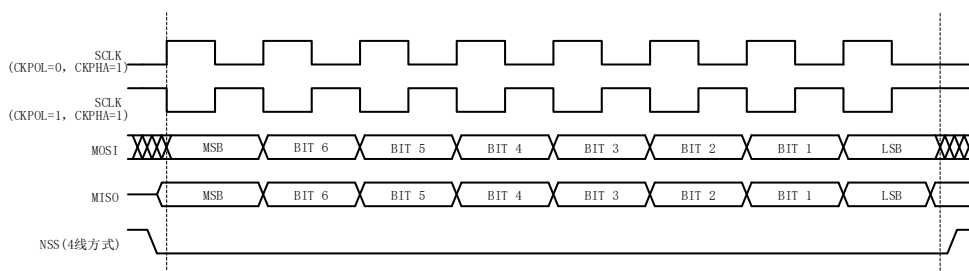


Figure 9-6 SDA/SCL Line Timing Diagram (SPI\_CR0[CPHA] = 1)

## 9.3 SPI Registers

### 9.3.1 SPI\_CR0 (0x4030)

Bit	7	6	5	4	3	2	1	0
Name	SPIBSY	SPIMS	CPHA	CPOL	SLVSEL	NSSIN	SRMT	RXBMT
Type	R	R/W	R/W	R/W	R	R	R	R
Reset	0	0	0	0	0	1	1	1

Bit	Name	Description
[7]	SPIBSY	SPI Busy Flag 0: No data is transferring via SPI transfer. 1: Data is transferring via SPI.
[6]	SPIMS	Master/Slave Mode Selection 0: Slave 1: Master
[5]	CPHA	Clock Phase 0: Data received on leading edge and transmitted on trailing edge of active SCLK. 1: Data transmitted on leading edge and received on trailing edge of active SCLK.
[4]	CPOL	Clock Idle Polarity 0: Low level in idle state. 1: High level in idle state.
[3]	SLVSEL	NSS Select Flag This bit is set to “1” when the filtered signal of NSS is low, indicating that the device is selected as slave. When NSS is high, this bit is cleared to “0”, indicating that the device is not selected as slave. 0: The device is NOT selected as slave. 1: The device is selected as slave.
[2]	NSSIN	NSS real-time signal, unfiltered.
[1]	SRMT	Shift Register Empty Flag (valid only in Slave Mode) 0: Data has been shifted out of the Transit Buffer into the shift register or SCLK changes. 1: There is no data in the shift register or transmit and receive buffer. Note: SPI_CR0[SRMT] = 1 in Master Mode.
[0]	RXBMT	Receive Buffer Empty Flag (valid only in Slave Mode) 0: New data in the receive buffer has not been read. 1: Data has been read and there is no new data in the receive buffer. Note: SPI_CR0[RXBMT] = 1 in Master Mode.

Notes: Clock phase and idle polarity modes SPI\_CR0[CPHA:CPOL]:

- 00: Receive data on rising edge, and send data on falling edge. Idle level is low.
- 01: Send data on rising edge, and receive data on falling edge. Idle level is high.
- 10: Send data on rising edge, and receive data on falling edge. Idle level is low.
- 11: Receive data on rising edge, and send data on falling edge. Idle level is high.

### 9.3.2 SPI\_CR1 (0x4031)

Bit	7	6	5	4	3	2	1	0
Name	SPIIF	WCOL	MODF	RXOVRN	NSSMOD		TXBMT	SPIEN
Type	R/W0	R/W0	R/W0	R/W0	R/W	R/W	R	R/W
Reset	0	0	0	0	0	0	1	0

Bit	Name	Description
-----	------	-------------

[7]	SPIIF	<p>SPI Interrupt Flag</p> <p>This bit is set to “1” by hardware each time after a data frame (8-bit) is transferred.</p> <p>Read:</p> <p>0: No Interrupt Pending .</p> <p>1: Interrupt Pending</p> <p>Write:</p> <p>0: This bit is cleared to “0”.</p> <p>1: No effect.</p>
[6]	WCOL	<p>Write Conflict Interrupt Flag</p> <p>When SPI_CR1[TXBMT] is “0”, a write to SPI_DR sets this bit to 1.</p> <p>This bit can be cleared to “0” by software only.</p> <p>Read:</p> <p>0: No Interrupt Pending</p> <p>1: Interrupt Pending</p> <p>Write:</p> <p>0: This bit is cleared to “0”.</p> <p>1: No effect.</p>
[5]	MODF	<p>Master Mode Fault Interrupt Flag</p> <p>This bit is set to “1” when a master mode conflict is detected (SPI_CR0[NSSIN] = 0, SPI_CR1[SPIMS] = 1 and SPI_CR1[NSSMOD] = 01).</p> <p>This bit can be cleared to “0” by software only.</p> <p>Read:</p> <p>0: No Interrupt Pending</p> <p>1: Interrupt Pending</p> <p>Write:</p> <p>0: This bit is cleared to “0”.</p> <p>1: No effect.</p>
[4]	RXOVRN	<p>Receive Overflow Interrupt Flag (Slave Mode only)</p> <p>This bit is set to “1” by hardware (and generates a SPI interrupt) when the Receive Buffer still holds unread data from a previous transfer and the last bit of the current transfer has been shifted into the SPI shift register. This bit cannot be cleared to “0” automatically by hardware, and can be cleared by software only.</p> <p>Read:</p> <p>0: No Interrupt Pending</p> <p>1: Interrupt Pending</p> <p>Write:</p> <p>0: This bit is cleared to “0”.</p> <p>1: No effect.</p>
[3:2]	NSSMOD	<p>SPI Mode Selection</p> <p>00: 3-Wire Slave or 3-wire Master Mode. NSS signal is not routed to a port pin.</p> <p>01: 4-Wire Slave or Multi-Master Mode (Default). NSS pin is configured as an input.</p> <p>1X: 4-Wire Single-Master Mode. NSS pin is configured as output and outputs SPI_CR1[2] value.</p>
[1]	TXBMT	<p>Transmit Buffer Empty Flag</p> <p>This bit is cleared to “0” when new data is written to the Transit Buffer. It is set to “1” when the data in the Transit Buffer is transferred to the SPI shift register, indicating that it is safe to write a new byte to the transmit buffer.</p> <p>0: A new byte is written to the transmit buffer.</p> <p>1: Data in the transmit buffer has been transferred to the shift register.</p>
[0]	SPIEN	<p>SPI Enable</p> <p>0: Disable</p> <p>1: Enable</p>

**9.3.3 SPI\_CLK (0x4032)**

Bit	7	6	5	4	3	2	1	0
Name	SPI_CLK							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	SPI_CLK	SPI Baud Rate Setting This bit is valid in master mode only, and can be written only when SPI_CR1[SPIEN] = 0. Baud rate = SYSCLK/2/(SPI_CLK + 1) Example: If baud rate = 2400kHz, then SPI_CLK = (24M/2/2400k) - 1 = 4, i.e. 0x04. Note: When MDU PI/PID and slave SPI are active at the same time (using DMA transfer), the master SPI Baud Rate shall be less than 600kHz to prevent erroneous data transmitted from the slave SPI.						

**9.3.4 SPI\_DR (0x4033)**

Bit	7	6	5	4	3	2	1	0
Name	SPI_DR							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	SPI_DR	SPI Data Register SPI_DR Register is used to transmit and receive SPI data. Read: Receive the data of Receive Buffer Write: Write the data into Transit Buffer and initiate a transfer						

## 10 UART

### 10.1 UART Introduction

UART is a full-duplex or half-duplex serial data exchange interface as shown in Figure 10-1. The baud rate is configurable and supports DMA transmission. Figure 10-2 depicts the UART timing.

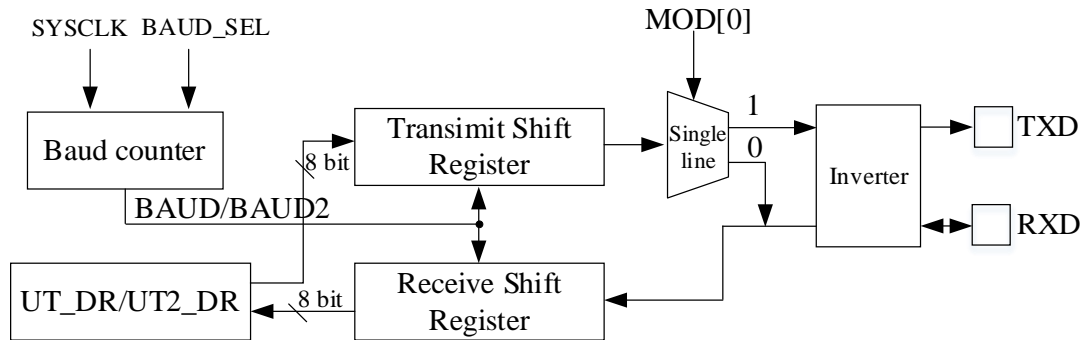


Figure 10-1 UART Block Diagram

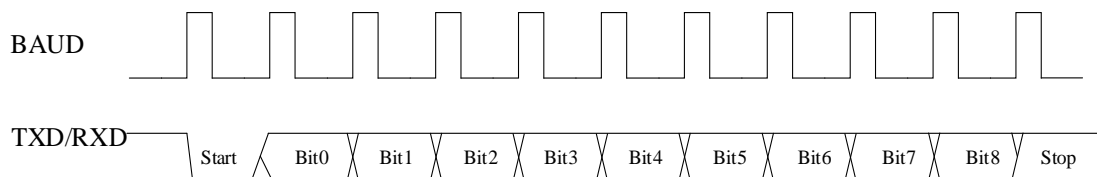


Figure 10-2 UART Timing Diagram

### 10.2 UART Operations

The corresponding registers shall be enabled before using UART feature. See section 22.3.16 PH\_SEL (0x404C) ([6] and [5] bits) ~ section 22.3.17 PH\_SEL1 (0x404D) ([7:6] bit) for details.

#### 10.2.1 UART1 Operating Instructions

##### 10.2.1.1 UART1 Mode0

UART1 mode0 works in single-wire half-duplex mode. RXD pin is configured as both an output (Transmit Data Bus) and an input (Receive Data Bus). It uses a total of 10 bits (1-bit start, 8-bit data, 1-bit stop) to receive or transmit data. The baud rate is configured by UT\_BAUD[BAUD].

**Sending Data:** Write the data to UT\_DR and clear UT\_CR[TI]. RXD outputs 10-bit data. UT\_CR[TI] is set to “1” after the transmission is completed.

**Receiving Data:** Set UT\_CR[REN] to “1” to receive the data and clear UT\_CR[RI]. The data is received via RXD. After the data is received, UT\_CR[RI] is set to “1” and UT\_DR is read to obtain the data.

##### 10.2.1.2 UART1 Mode1

UART1 mode1 works in full/half duplex mode. TXD pin is configured as an output (Transmit Data Bus),

and RXD as an input (Receive Data Bus). It uses a total of 10 bits (1-bit start, 8-bit data, 1-bit stop) to receive or transmit data. The baud rate is configured by UT\_BAUD[BAUD].

**Sending Data:** Write the data to UT\_DR and clear UT\_CR[TI]. TXD outputs 10-bit data. UT\_CR[TI] is set to “1” after the transmission is completed.

**Receiving Data:** Set UT\_CR[REN] to “1” to receive the data and clear UT\_CR[RI]. The data is received via RXD. After the data is received, UT\_CR[RI] is set to “1” and UT\_DR is read to obtain the data.

### 10.2.1.3 UART1 Mode2

UART1 mode2 works in single-wire half-duplex mode. RXD pin is configured as both an output (Transmit Data Bus) and an input (Receive Data Bus). It uses a total of 11 bits (1-bit start, 9-bit data and 1-bit stop) to receive or transmit data. The baud rate is configured by UT\_BAUD[BAUD].

**Sending Data:** Write the first 8 bits of the data to UT\_DR and the 9<sup>th</sup> bit to UT\_CR[TB8], and clear UT\_CR[TI]. TXD outputs 11-bit data. UT\_CR[TI] is set to “1” after the transmission is completed.

**Receiving Data:** Set UT\_CR[REN] to “1” to receive the data and clear UT\_CR[RI]. The data is received via RXD. After the data is received, UT\_CR[RI] is set to “1”. UT\_CR[RB8] stores the 9<sup>th</sup> bit of the data, and UT\_DR stores the first 8 bits.

### 10.2.1.4 UART1 Mode3

UART1 mode3 works in full/half duplex mode. TXD pin is configured as an output (Transmit Data Bus), and RXD as an input (Receive Data Bus). It uses a total of 11 bits (1-bit start, 9-bit data, 1-bit stop) to receive or transmit data. The baud rate is configured by UT\_BAUD[BAUD].

**Sending Data:** Write the first 8 bits of the data to UT\_DR and the 9<sup>th</sup> bit to UT\_CR[TB8], and clear UT\_CR[TI]. TXD outputs 11-bit data. UT\_CR[TI] is set to “1” after the transmission is completed.

**Receiving Data:** Set UT\_CR[REN] to “1” to receive the data and clear UT\_CR[RI]. The data is received via RXD. After the data is received, UT\_CR[RI] is set to “1”. UT\_CR[RB8] stores the 9<sup>th</sup> bit of the data, and UT\_DR stores the first 8 bits.

### 10.2.1.5 UART1 Interrupt Sources

UART1 interrupt sources include:

- After UART1 sends the data, UT\_CR[TI] is set to “1” by hardware.
- After UART1 receives the data and STOP, UT\_CR[RI] is set to “1” by hardware.

## 10.2.2 UART2 Operating Instructions

### 10.2.2.1 UART2 Mode0

UART2 mode0 works in single-wire half-duplex mode. RXD pin is configured as both an output (Transmit Data Bus) and an input (Receive Data Bus). It uses a total of 10 bits (1-bit start, 8-bit data, 1-bit

stop) to receive or transmit data. The baud rate is configured by UT2\_BAUD[BAUD2].

**Sending Data:** Write the data to UT2\_DR and clear UT2\_CR[UT2TI]. RXD outputs 10-bit data. UT2\_CR[UT2TI] is set to “1” after the transmission is completed.

**Receiving Data:** Set UT2\_CR[UT2REN] to “1” to receive the data and clear UT2\_CR[UT2RI]. The data is received via RXD. After the data is received, UT2\_CR[UT2RI] is set to “1” and UT2\_DR is read to obtain the data.

#### **10.2.2.2 UART2 Mode1**

UART2 mode1 works in full/half duplex mode. TXD pin is configured as an output (Transmit Data Bus), and RXD as an input (Receive Data Bus). It uses a total of 10 bits (1-bit start, 8-bit data, 1-bit stop) to receive or transmit data. The baud rate is configured by UT2\_BAUD[BAUD2].

**Sending Data:** Write the data to UT2\_DR and clear UT2\_CR[UT2TI]. TXD outputs 10-bit data. UT2\_CR[UT2TI] is set to “1” after the transmission is completed.

**Receiving Data:** Set UT2\_CR[UT2REN] to “1” to receive the data and clear UT2\_CR[UT2RI]. The data is received via RXD. After the data is received, UT2\_CR[UT2RI] is set to “1” and UT2\_DR is read to obtain the data.

#### **10.2.2.3 UART2 Mode2**

UART2 mode2 works in single-wire half-duplex mode. RXD pin is configured as both an output (Transmit Data Bus) and an input (Receive Data Bus). It uses a total of 11 bits (1-bit start, 9-bit data, and 1-bit stop) to receive or transmit data. The baud rate is configured by UT2\_BAUD[BAUD2].

**Sending Data:** Write the first 8 bits of the data to UT2\_DR and the 9<sup>th</sup> bit to UT2\_CR[UT2TB8], and clear UT2\_CR[UT2TI]. TXD outputs 11-bit data. UT2\_CR[UT2TI] is set to “1” after the transmission is completed.

**Receiving Data:** Set UT2\_CR[UT2REN] to “1” to receive the data and clear UT2\_CR[UT2RI]. The data is received via RXD. After the data is received, UT2\_CR[UT2RI] is set to “1”. UT2\_CR[UT2RB8] stores the 9<sup>th</sup> bit of the data, and UT2\_DR stores the first 8 bits.

#### **10.2.2.4 UART2 Mode3**

UART2 mode3 works in full/half duplex mode. TXD pin is configured as an output (Transmit Data Bus), and RXD as an input (Receive Data Bus). It uses a total of 11 bits (1-bit start, 9-bit data, 1-bit stop) to receive or transmit data. The baud rate is configured by UT2\_BAUD[BAUD2].

**Sending Data:** Write the first 8 bits of the data to UT2\_DR and the 9<sup>th</sup> bit to UT2\_CR[UT2TB8], and clear UT2\_CR[UT2TI]. TXD outputs 11-bit data. UT2\_CR[UT2TI] is set to “1” after the transmission is completed.



Receiving Data: Set UT2\_CR[UT2REN] to “1” to receive the data and clear UT2\_CR[UT2RI]. The data is received via RXD. After the data is received, UT2\_CR[UT2RI] is set to “1”. UT2\_CR[UT2RB8] stores the 9<sup>th</sup> bit of the data, and UT2\_DR stores the first 8 bits.

### 10.2.2.5 UART2 Interrupt Sources

UART2 interrupt sources include:

- After UART2 sends data, UT2\_CR[UT2TI] is set to “1” by hardware.
- After UART2 receives data and STOP, UT2\_CR[UT2RI] is set to “1” by hardware.

## 10.3 UART1 Registers

### 10.3.1 UT\_CR (0x98)

Bit	7	6	5	4	3	2	1	0
Name	MOD		SM2	REN	TB8	RB8	TI	RI
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:6]	MOD	Mode Selection 00: Mode0 01: Mode1 10: Mode2 11: Mode3						
[5]	SM2	Communication Mode Selection 0: Single-device Communication 1: Multi-device Communication						
[4]	REN	Receive Enable 0: Disable 1: Enable						
[3]	TB8	Bit9 of the Transmitted Data in Mode2 and Mode3						
[2]	RB8	Bit9 of the Received Data in Mode2 and Mode3						
[1]	TI	Data Transmitting Completed Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: Interrupt Pending						
[0]	RI	Data Receiving Completed Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: Interrupt Pending						

### 10.3.2 UT\_DR (0x99)

Bit	7	6	5	4	3	2	1	0	
Name	UT_DR								
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Reset	0	0	0	0	0	0	0	0	
Bit	Name	Description							
[7:0]	UT_DR	Transmit/ Receive Data Read: Data received Write: Data to be transmitted Note: The UART1 data buffer consists of two independent buffers, i.e., a receive buffer and a transmit buffer, which can send and receive data at the same time. The transmit buffer can be written only but not read, while the receive buffer can be read only but not written. Both buffers share a same address.							

### 10.3.3 UT\_BAUD (0x9A, 0x9B)

UT_BAUDH(0x9B)									
Bit	15	14	13	12	11	10	9	8	
Name	BAUD_SEL	UART_RX_INV	UART_TX_INV	RSV	BAUD[11:8]				
Type	R/W	R/W	R/W	-	R/W	R/W	R/W	R/W	
Reset	0	0	0	-	0	0	0	0	
UT_BAUDL(0x9A)									
Bit	7	6	5	4	3	2	1	0	
Name	BAUD[7:0]								
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Reset	1	0	0	1	1	0	1	1	
Bit	Name	Description							
[15]	BAUD_SEL	Frequency Multiplier Enable 0: Disable 1: Enable							
[14]	UART_RX_INV	Receive Inverting Enable 0: Disable 1: Enable							
[13]	UART_TX_INV	Transmit Inverting Enable 0: Disable 1: Enable							
[12]	RSV	Reserved							
[11:0]	BAUD	Baud Rate Setting $\text{Baud rate} = \text{SYSCLK} / (16 / (1 + \text{UT\_BAUD}[\text{BAUD\_SEL}])) / (\text{UT\_BAUD}[\text{BAUD}] + 1)$ Example: If baud rate = 9600 and UT_BAUD[BAUD_SEL] = 0, then $\text{UT\_BAUD}[\text{BAUD}] = (24\text{M} / 16 / 9600 / (1 + 0)) - 1 = 155, \text{ i.e., } 0x9B$							

## 10.4 UART2 Registers

### 10.4.1 UT2\_CR (0xD8)

Bit	7	6	5	4	3	2	1	0	
Name	UT2MOD		UT2SM2	UT2REN	UT2TB8	UT2RB8	UT2TI	UT2RI	
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W0	R/W0	
Reset	0	0	0	0	0	0	0	0	
Bit	Name	Description							
[7:6]	UT2MOD	Mode Selection 00: Mode0							

		01: Mode1 10: Mode2 11: Mode3
[5]	UT2SM2	Communication Mode Selection 0: Single-device Communication 1: Multi-device Communication
[4]	UT2REN	Receive Enable 0: Disable 1: Enable
[3]	UT2TB8	Bit9 of the Transmitted Data in Mode2 and Mode3
[2]	UT2RB8	Bit9 of the Received Data in Mode2 and Mode3
[1]	UT2TI	Data Transmitting Completed Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to "0". 1: Interrupt Pending
[0]	UT2RI	Data Receiving Completed Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to "0". 1: Interrupt Pending

#### 10.4.2 UT2\_DR (0x89)

Bit	7	6	5	4	3	2	1	0
Name	UT2_DR							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	UT2_DR	Transmit/Receive Data Read: Data received Write: Data to be transmitted Note: The UART2 data buffer consists of two independent buffers, i.e., a receive buffer and a transmit buffer, which can send and receive data at the same time. The transmit buffer can be written only but not read, while the receive buffer can be read only but not written. Both buffers share a same address.						

#### 10.4.3 UT2\_BAUD (0x4042, 0x4043)

UT2_BAUDH(0x4042)								
Bit	15	14	13	12	11	10	9	8
Name	BAUD2_SEL	UART2_RX_INV	UART2_TX_INV	UART2IEN	BAUD2[11:8]			
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
UT2_BAUDL(0x4043)								
Bit	7	6	5	4	3	2	1	0
Name	BAUD2[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	1	0	0	1	1	0	1	1
Bit	Name	Description						

[15]	BAUD2_SEL	Frequency Multiplier Enable 0: Disable 1: Enable
[14]	UART2_RX_INV	Receive Inverting Enable 0: Disable 1: Enable
[13]	UART2_TX_INV	Transmit Inverting Enable 0: Disable 1: Enable
[12]	UART2IEN	UART2 Interrupt Enable 0: Disable 1: Enable
[11: 0]	BAUD2	Baud Rate Setting Baud rate = $\text{SYSCLK}/(16/(1 + \text{UT2\_BAUD}[\text{BAUD2\_SEL}]))/(\text{UT2\_BAUD}[\text{BAUD2}] + 1)$ Example: If baud rate = 9600 and $\text{UT2\_BAUD}[\text{BAUD\_SEL}] = 0$ , then $\text{UT2\_BAUD}[\text{BAUD2}] = (24\text{M}/16/9600/(1 + 0)) - 1 = 155$ , i.e., 0x9B

## 11 MDU

### 11.1 MDU Introduction

MDU is a built-in computing co-processor that assists the CPU in processing complex operations efficiently. It supports multiplication, division, trigonometric operation, LPF operation and PID operation. MDU module can be invoked in different interrupt services and master programs, and the results are independent from each other.

### 11.2 MDU Features

The MDU module has the following features:

- Support invocation with nested interrupt
- Hardware acceleration to reduce CPU load
- Support the following modes:
  - 16-bit signed multiplication
  - 16-bit signed multiplication (result shifted left by one-bit)
  - 16-bit unsigned multiplication
  - 32-bit/16-bit unsigned division
  - Low-pass filter (LPF)
  - Coordinate transformation (SIN/COS)
  - Arctangent (ATAN)
  - PI/PID

### 11.3 MDU Instructions

#### 11.3.1 MDU Operations

MDU is operated as follows.

1. Configure MDU\_CR[MDUMOD] register to select computing mode of the MDU module;
2. Write the data to the associated computing units, and configure MDU\_CR[MDUSTA] to select computing unit of the MDU module, and start MDU computing;
3. Wait for MDU\_CR[MDUBUSY] to be cleared to “0” by hardware.

Note: When using MDU, ensure that the computing mode and other data have been written before configuring MDU\_CR[MDUSTA].

#### 11.3.2 16-bit Signed Multiplication with the Result Shifted Left by One-bit

When MDU\_CR[MDUMOD] = 000, MDU module works in the 16-bit signed multiplication mode with the result shifted left by one-bit. As shown in Table 11-1, after 16-bit signed data is written to MULx\_MA and MULx\_MB as multiplicand and multiplier respectively, 32-bit signed data is obtained by the product

shifting left by one bit. The result is accessed by reading MULx\_MC register.

Table 11-1 Register Definitions in 16-bit Signed Multiplication Mode with Result Shifted Left by One-bit

Data Register	Input	Output
MULx_MA	Multiplicand	-
MULx_MB	Multiplier	-
MULx_MC	-	Product

### 11.3.3 16-bit Signed Multiplication

When MDU\_CR[MDUMOD] = 001, MDU module works in the 16-bit signed multiplication mode. As shown in Table 11-2, 31-bit signed data is obtained after 16-bit signed data is written to MULx\_MA and MULx\_MB as multiplicand and multiplier respectively. The result is accessed by reading MULx\_MC register.

Table 11-2 Register Definitions in 16-bit Signed Multiplication Mode

Data Register	Input	Output
MULx_MA	Multiplicand	-
MULx_MB	Multiplier	-
MULx_MC	-	Product

### 11.3.4 16-bit Unsigned Multiplication

When MDU\_CR[MDUMOD] = 010, MDU module works in the 16-bit unsigned multiplication mode. As shown in Table 11-3, 32-bit unsigned data is obtained after 16-bit unsigned data is written to MULx\_MA and MULx\_MB as multiplicand and multiplier respectively. The result is accessed by reading MULx\_MC register.

Table 11-3 Register Definitions in 16-bit Unsigned Multiplication Mode

Data Register	Input	Output
MULx_MA	Multiplicand	-
MULx_MB	Multiplier	-
MULx_MC	-	Product

### 11.3.5 32-bit/16-bit Unsigned Division

When MDU\_CR[MDUMOD] = 011, MDU module works in the 32-bit/16-bit unsigned division mode. As shown in Table 11-4, 32-bit unsigned quotient and 16-bit unsigned remainder is obtained after 32-bit unsigned dividend and a 16-bit unsigned divisor are written to DIVx\_DA and DIVx\_DB registers respectively. The quotient and remainder are accessed by reading DIVx\_DQ and DIVx\_DR registers respectively.

Table 11-4 Register Definitions in the Unsigned Division Mode

Data Register	Input	Output
DIVx_DA	Dividend	-
DIVx_DB	Divisor	-
DIVx_DQ	-	Quotient
DIVx_DR	-	Remainder

### 11.3.6 LPF

When MDU\_CR[MDUMOD] = 110, MDU module works in LPF mode.

The calculation formula of LPF is:

$$Y_k = Y_{k-1} + K \times (X_k - Y_{k-1})$$

Wherein,

$Y_k$ : Filtered value

$Y_{k-1}$ : Previous filtered output

$K$ : Filter coefficient

$X_k$ : Value to be filtered

As shown in Table 11-5,  $Y_k$  and  $Y_{k-1}$  are 32-bit signed data,  $X_k$  and  $K$  are 16-bit signed data.  $Y_k$  is obtained after  $Y_{k-1}$  is written to LPFx\_Y,  $K$  to LPFx\_K and  $X_k$  to LPFx\_X, and is accessed by reading LPFx\_Y.

Table 11-5 Register Definitions in LPF Mode

Data Register	Input	Output
LPFx_X	$X_k$	-
LPFx_K	$K$	-
LPFx_Y	$Y_{k-1}$	$Y_k$

### 11.3.7 Coordinate Transformation

When MDU\_CR[MDUMOD] = 100, MDU module works in Coordinate Transformation mode. As shown in Figure 11-1, the coordinate transformation converts the components  $cos_i$  and  $sin_i$  of vector A under the x-y axis to the components  $cos_o$  and  $sin_o$  under the x'-y' axis, with the x'-y' axis lagging the x-y axis by  $\theta$ .

The formula for coordinate transformation is:

$$cos_o = cos_i \times cos \theta - sin_i \times sin \theta$$

$$sin_o = cos_i \times sin \theta + sin_i \times cos \theta$$

In particular, when  $sin_i = 0$ , the coordinate transformation is a sine and cosine calculation with  $cos_i$  as the amplitude, calculated as:

$$cos_o = cos_i \times cos \theta$$

$$sin_o = cos_i \times sin \theta$$

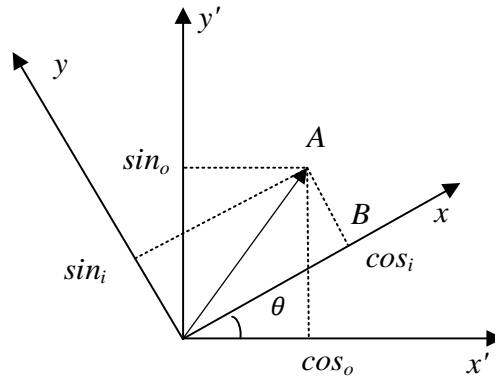


Figure 11-1 Coordinate Transformation

As shown in Table 11-6,  $cos_i$ ,  $sin_i$ ,  $\theta$ ,  $cos_o$  and  $sin_o$  are all 16-bit signed data.  $cos_i$  is written to SCATx\_COS,  $sin_i$  to SCATx\_SIN and  $\theta$  to SCATx\_THE to calculate  $cos_o$  and  $sin_o$ . The results  $cos_o$  and  $sin_o$  are accessed by reading SCATx\_RES1 and SCATx\_RES2 respectively.

Table 11-6 Register Definitions in the Coordinate Transformation Mode

Data Register	Input	Output
SCATx_COS	$cos_i$	-
SCATx_SIN	$sin_i$	-
SCATx_THE	$\theta$	-
SCATx_RES1	-	$cos_o$
SCATx_RES2	-	$sin_o$

### 11.3.8 Arctangent

When MDU\_CR[MDUMOD] = 101, MDU module works in arctangent (ATAN) mode.

ATAN calculates the amplitude and angle of a vector based on sine and cosine inputs. The calculation formula is:

$$U = \sqrt{(U \sin \theta)^2 + (U \cos \theta)^2}$$

$$\theta = \tan^{-1} \left( \frac{U \sin \theta}{U \cos \theta} \right)$$

Wherein,

$U \sin \theta$ : Sin component of the vector

$U \cos \theta$ : Cosine component of the vector

$\theta$ : Calculated vector angle

$U$ : Calculated vector amplitude

As shown in Table 11-7,  $U \cos \theta$  and  $U \sin \theta$ ,  $U$  and  $\theta$  are 16-bit signed data.  $U \cos \theta$  is written to SCATx\_COS and  $U \sin \theta$  to SCATx\_SIN to calculate  $U$  and  $\theta$ .  $U$  and  $\theta$  are accessed by reading SCATx\_RES1 and SCATx\_RES2 respectively.



Table 11-7 Register Definitions in ATAN Mode

Data Register	Input	Output
SCATx COS	$U\cos\theta$	-
SCATx SIN	$U\sin\theta$	-
SCATx RES1	-	$U$
SCATx RES2	-	$\theta$

### 11.3.9 PI/PID

#### 11.3.9.1 PI/PID Introduction

PI/PID regulator is a linear controller, where the output is generated by linear combination of error proportional, integral and differential actions, and then implemented by an actuator. In motor control system, it is used to for speed and position control.

PI algorithm:

$$U_k = U_{k-1} + Kp \times (E_k - E_{k-1}) + Ki \times E_k$$

PID algorithm:

$$U_k = U_{k-1} + Kp \times (E_k - E_{k-1}) + Ki \times E_k + Kd \times (E_k - 2 \times E_{k-1} + E_{k-2})$$

Wherein,

$U_k$ : Output for round k of calculation

$U_{k-1}$ : Output for round k-1 of calculation

$E_k$ : Deviation for round k of input

$E_{k-1}$  and  $E_{k-2}$ : Deviations for round k-1 and round k-2 of calculation

$K_p$ ,  $K_i$  and  $K_d$ : Proportional (P), integral (I) and differential (D) coefficients of regulator

The maximum  $U_k$  is represented as  $PIx\_UKMAX$  ( $x=0\sim3$ ) and the minimum value as  $PIx\_UKMIN$

#### 11.3.9.2 PI/PID Features

- Parameter range is configurable
- Support multiple invocations but not with nested interrupt
- Produce a 32-bit result  $PIx\_UK$
- Results are read after Busy Flag is reset to “0”.

#### 11.3.9.3 PI/PID Operations

1. Initialize MDU before the operations, and configure  $K_p$ ,  $K_i$ ,  $K_d$  and the maximum and minimum values of  $U_k$ ;
2. Set  $MDU\_CR[MDUMOD]$  to 111, and then select  $Comp\_Unit0$  and  $Comp\_Unit1$  as PI Mode, and  $Comp\_Unit2$  and  $Comp\_Unit3$  as PID Mode. Later, configure  $MDU\_CR[MDUSTA]$  bit to select the desired computing unit and start PI/PID computing. At this time, busy flag  $MDU\_CR[MDUBUSY]$  is automatically set to “1”.

3. Read MDU\_CR[MDUBUSY] bit by software. When this bit is 0, it indicates that the calculation is completed, and calculation result PI<sub>x</sub>\_UK is updated.
4. Read PI<sub>x</sub>\_UK to obtain the output.

Notes:

- The data format of PI<sub>x</sub>\_KP is Q12 and that of other registers are Q15.
- PI<sub>x</sub>\_UK and PI<sub>x</sub>\_EK1 values default to the previous calculated U<sub>k</sub> and E<sub>k</sub>. The related values change after PI<sub>x</sub>\_EK1 and PI<sub>x</sub>\_UK are written.
- When PI controller is invoked repeatedly, relevant parameters shall be saved after each PI operation, and initialized before the next PI operation. Initialization codes are shown as below:

```

PIx_KP = KP;           //Initialize Kp
PIx_KI = KI;          //Initialize Ki
PIx_KD = KD;          //Initialize Kd
PIx_UKMAX = UKMAX;    //Initialize maximum output
PIx_UKMIN = UKMIN;    //Initialize minimum output
PIx_EK1 = X;          //Initialize Ek-1
PIx_UKH = Y1;         //Initialize 16 high-order bits of Uk-1
PIx_UKL = Y2;         //Initialize 16 low-order bits of Uk-1

```

## 11.4 MDU Registers

### 11.4.1 MDU\_CR (0xC1)

Bit	7	6	5	4	3	2	1	0
Name	MDUBUSY	MDUSTA				MDUMOD		
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	MDUBUSY	MDU Busy Flag A write of MDU_CR[6:3] to this bit starts MDU module. The bit is set to “1” after MDU completes operations.						
[6:3]	MDUSTA	The bit is used to configure computing unit of the MDU. Four options are available. MDU module starts operation after initiating the computing. 0001: Comp_Unit0 activated 0010: Comp_Unit1 activated 0100: Comp_Unit2 activated 1000: Comp_Unit3 activated						
[2:0]	MDUMOD	MDU Mode Selection 000: 16-bit Signed Multiplication (the result shifted left by one-bit) 001: 16-bit Signed Multiplication 010: 16-bit Unsigned Multiplication 011: 32-bit/16-bit Unsigned Division 100: Coordinate Transformation (SIN/COS) 101: ATAN 110: LPF 111:PI/PID; The mode of PI and PID is determined by the computing unit. The computing unit 0 and 1 select PI mode, and the computing unit 2 and 3 select PID mode.						

**11.4.2 MUL0\_MA (0x0FA0, 0x0FA1)**

MUL0 MAH(0x0FA0)								
Bit	15	14	13	12	11	10	9	8
Name	MUL0 MA[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL0 MAL(0x0FA1)								
Bit	7	6	5	4	3	2	1	0
Name	MUL0 MA[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	MUL0_MA	Data register A of MUL0; Multiplicand of the multiplication						

**11.4.3 MUL0\_MB (0x0FA2, 0x0FA3)**

MUL0 MBH(0x0FA2)								
Bit	15	14	13	12	11	10	9	8
Name	MUL0 MB[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL0 MBL(0x0FA3)								
Bit	7	6	5	4	3	2	1	0
Name	MUL0 MB[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	MUL0_MB	Data register B of MUL0; Multiplier of the multiplication						

**11.4.4 MUL0\_MC (0x0FA4, 0x0FA5, 0x0FA6, 0x0FA7)**

MUL0 MCHH(0x0FA4)								
Bit	31	30	29	28	27	26	25	24
Name	MUL0 MC[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL0 MCHL(0x0FA5)								
Bit	23	22	21	20	19	18	17	16
Name	MUL0 MC[13:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL0 MCLH(0x0FA6)								
Bit	15	14	13	12	11	10	9	8
Name	MUL0 MC[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL0 MCLL(0x0FA7)								
Bit	7	6	5	4	3	2	1	0
Name	MUL0 MC[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	MUL0_MC	Product of MUL0. The 16 high-order bits of the data is held by MUL0_MCH and the 16 low-order bits by MUL0_MCL.						

**11.4.5 MUL1\_MA (0x0F98, 0x0F99)**

MUL1 MAH(0x0F98)								
Bit	15	14	13	12	11	10	9	8
Name	MUL1_MA[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL1 MAL(0x0F99)								
Bit	7	6	5	4	3	2	1	0
Name	MUL1_MA[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	MUL1_MA	Data register A of MUL1; Multiplicand of the multiplication						

**11.4.6 MUL1\_MB (0x0F9A, 0x0F9B)**

MUL1 MBH(0x0F9A)								
Bit	15	14	13	12	11	10	9	8
Name	MUL1_MB[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL1 MBL(0x0F9B)								
Bit	7	6	5	4	3	2	1	0
Name	MUL1_MB[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	MUL1_MB	Data register B of MUL1; Multiplier of the multiplication						

**11.4.7 MUL1\_MC (0x0F9C, 0x0F9D, 0x0F9E, 0x0F9F)**

MUL1 MCHH(0x0F9C)								
Bit	31	30	29	28	27	26	25	24
Name	MUL1_MC[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL1 MCHL(0x0F9D)								
Bit	23	22	21	20	19	18	17	16
Name	MUL1_MC[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL1 MCLH(0x0F9E)								
Bit	15	14	13	12	11	10	9	8
Name	MUL1_MC[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL1 MCLL(0x0F9F)								
Bit	7	6	5	4	3	2	1	0
Name	MUL1_MC[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	MUL1_MC	Product of MUL1. The 16 high-order bits of the data is held by MUL1_MCH and the 16 low-order bits by MUL1_MCL.						

**11.4.8 MUL2\_MA (0x0F40, 0x0F41)**

MUL2 MAH(0x0F40)								
Bit	15	14	13	12	11	10	9	8
Name	MUL2_MA[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL2 MAL(0x0F41)								
Bit	7	6	5	4	3	2	1	0
Name	MUL2_MA[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	MUL2_MA	Data register A of MUL2; Multiplicand of the multiplication						

**11.4.9 MUL2\_MB (0x0F42, 0x0F43)**

MUL2 MBH(0x0F42)								
Bit	15	14	13	12	11	10	9	8
Name	MUL2_MB[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL2 MBL(0x0F43)								
Bit	7	6	5	4	3	2	1	0
Name	MUL2_MB[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	MUL2_MB	Data register B of MUL2; Multiplier of the multiplication						

**11.4.10 MUL2\_MC (0x0F44, 0x0F45, 0x0F46, 0x0F47)**

MUL2 MCHH(0x0F44)								
Bit	31	30	29	28	27	26	25	24
Name	MUL2_MC[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL2 MCHL(0x0F45)								
Bit	23	22	21	20	19	18	17	16
Name	MUL2_MC[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL2 MCLH(0x0F46)								
Bit	15	14	13	12	11	10	9	8
Name	MUL2_MC[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL2 MCLL(0x0F47)								
Bit	7	6	5	4	3	2	1	0
Name	MUL2_MC[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	MUL2_MC	Product of MUL2. The 16 high-order bits of the data is held by MUL2_MCH and the 16 low-order bits by MUL2_MCL.						

**11.4.11 MUL3\_MA (0x0F38, 0x0F39)**

MUL3 MAH(0x0F38)								
Bit	15	14	13	12	11	10	9	8
Name	MUL3_MA[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL3 MAL(0x0F39)								
Bit	7	6	5	4	3	2	1	0
Name	MUL3_MA[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	MUL3_MA	Data register A of MUL3; Multiplicand of the multiplication						

**11.4.12 MUL3\_MB (0x0F3A, 0x0F3B)**

MUL3 MBH(0x0F3A)								
Bit	15	14	13	12	11	10	9	8
Name	MUL3_MB[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL3 MBL(0x0F3B)								
Bit	7	6	5	4	3	2	1	0
Name	MUL3_MB[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	MUL3_MB	Data register B of MUL3; Multiplier of the multiplication						

**11.4.13 MUL3\_MC (0x0F3C, 0x0F3D, 0x0F3E, 0x0F3F)**

MUL3 MCHH(0x0F3C)								
Bit	31	30	29	28	27	26	25	24
Name	MUL3_MC[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL3 MCHL(0x0F3D)								
Bit	23	22	21	20	19	18	17	16
Name	MUL3_MC[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL3 MCLH(0x0F3E)								
Bit	15	14	13	12	11	10	9	8
Name	MUL3_MC[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
MUL3 MCLL(0x0F3F)								
Bit	7	6	5	4	3	2	1	0
Name	MUL3_MC[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	MUL3_MC	Product of MUL3. The 16 high-order bits of the data is held by MUL3_MCH and the 16 low-order bits by MUL3_MCL.						

**11.4.14 DIV0\_DA (0x0F8C, 0x0F8D, 0x0F8E, 0x0F8F)**

DIV0_DAHH(0x0F8C)								
Bit	31	30	29	28	27	26	25	24
Name	DIV0_DA[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV0_D AHL(0x0F8D)								
Bit	23	22	21	20	19	18	17	16
Name	DIV0_DA[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV0_D ALH(0x0F8E)								
Bit	15	14	13	12	11	10	9	8
Name	DIV0_DA[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV0_D ALL(0x0F8F)								
Bit	7	6	5	4	3	2	1	0
Name	DIV0_DA[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	DIV0_DA	Dividend of DIV0. The 16 high-order bits of the data is held by DIV0_DAH and the 16 low-order bits by DIV0_DAL.						

**11.4.15 DIV0\_DB (0x0F90, 0x0F91)**

DIV0_DBH(0x0F90)								
Bit	15	14	13	12	11	10	9	8
Name	DIV0_DB[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV0_D BL(0x0F91)								
Bit	7	6	5	4	3	2	1	0
Name	DIV0_DB[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	DIV0_DB	Data register B of DIV0; Divisor of the division						

**11.4.16 DIV0\_DQ (0x0F92, 0x0F93, 0x0F94, 0x0F95)**

DIV0_DQHH(0x0F92)								
Bit	31	30	29	28	27	26	25	24
Name	DIV0_DQ[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV0_D QHL(0x0F93)								
Bit	23	22	21	20	19	18	17	16
Name	DIV0_DQ[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

DIV0_DQLH(0x0F94)								
Bit	15	14	13	12	11	10	9	8
Name	DIV0_DQ[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV0_DQLL(0x0F95)								
Bit	7	6	5	4	3	2	1	0
Name	DIV0_DQ[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	DIV0_DQ[31:0]	Quotient of DIV0. The 16 high-order bits of the data is held by DIV0_DQH and the 16 low-order bits by DIV0_DQL.						

#### 11.4.17 DIV0\_DR (0x0F96, 0x0F97)

DIV0_DRH(0x0F96)								
Bit	15	14	13	12	11	10	9	8
Name	DIV0_DR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV0_DRL(0x0F97)								
Name	DIV0_DR[7:0]							
Bit	7	6	5	4	3	2	1	0
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	DIV0_DR	Remainder of DIV0						

#### 11.4.18 DIV1\_DA (0x0F80, 0x0F81, 0x0F82, 0x0F83)

DIV1_DAHH(0x0F80)								
Bit	31	30	29	28	27	26	25	24
Name	DIV1_DA[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV1_D AHL(0x0F81)								
Bit	23	22	21	20	19	18	17	16
Name	DIV1_DA[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV1_DALH(0x0F82)								
Bit	15	14	13	12	11	10	9	8
Name	DIV1_DA[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV1_DALL(0x0F83)								
Bit	7	6	5	4	3	2	1	0
Name	DIV1_DA[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	DIV1_DA	Dividend of DIV1. The 16 high-order bits of the data is held by DIV1_DAH and the 16 low-order bits by DIV1_DAL.						



**11.4.19 DIV1\_DB (0x0F84, 0x0F85)**

DIV1 DBH(0x0F84)								
Bit	15	14	13	12	11	10	9	8
Name	DIV1_DB[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV1 DBL(0x0F85)								
Bit	7	6	5	4	3	2	1	0
Name	DIV1_DB[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	DIV1_DB	Data register B of DIV1; Divisor of the division						

**11.4.20 DIV1\_DQ (0x0F86, 0x0F87, 0x0F88, 0x0F89)**

DIV1 DQHH(0x0F86)								
Bit	31	30	29	28	27	26	25	24
Name	DIV1_DQ[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV1 DQHL(0x0F87)								
Bit	23	22	21	20	19	18	17	16
Name	DIV1_DQ[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV1 DQLH(0x0F88)								
Bit	15	14	13	12	11	10	9	8
Name	DIV1_DQ[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV1 DQLL(0x0F89)								
Bit	7	6	5	4	3	2	1	0
Name	DIV1_DQ[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	DIV1_DQ	Quotient of DIV1. The 16 high-order bits of the data is held by DIV1_DQH and the 16 low-order bits by DIV1_DQL.						

**11.4.21 DIV1\_DR (0x0F8A, 0x0F8B)**

DIV1 DRH(0x0F8A)								
Bit	15	14	13	12	11	10	9	8
Name	DIV1_DR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV1 DRL(0x0F8B)								
Bit	7	6	5	4	3	2	1	0
Name	DIV1_DR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	DIV1_DR	Remainder of DIV1						

**11.4.22 DIV2\_DA (0x0F2C, 0x0F2D, 0x0F2E, 0x0F2F)**

DIV2 DAHH(0x0F2C)								
Bit	31	30	29	28	27	26	25	24
Name	DIV2_DA[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV2 DAHL(0x0F2D)								
Bit	23	22	21	20	19	18	17	16
Name	DIV2_DA[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV2 DALH(0x0F2E)								
Bit	15	14	13	12	11	10	9	8
Name	DIV2_DA[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV2 DALL(0x0F2F)								
Bit	7	6	5	4	3	2	1	0
Name	DIV2_DA[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	DIV2_DA	Dividend of DIV2. The 16 high-order bits of the data is held by DIV2_DA and the 16 low-order bits by DIV2_DA.						

**11.4.23 DIV2\_DB (0x0F30, 0x0F31)**

DIV2_DBH(0x0F30)								
Bit	15	14	13	12	11	10	9	8
Name	DIV2_DB[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV2_DBL(0x0F31)								
Bit	7	6	5	4	3	2	1	0
Name	DIV2_DB[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	DIV2_DB	Data register B of DIV2; Divisor of the division						

**11.4.24 DIV2\_DQ (0x0F32, 0x0F33, 0x0F34, 0x0F35)**

DIV2 DQHH(0x0F32)								
Bit	31	30	29	28	27	26	25	24
Name	DIV2_DQ[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV2 DQHL(0x0F33)								
Bit	23	22	21	20	19	18	17	16
Name	DIV2_DQ[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

DIV2_DQLH(0x0F34)								
Bit	15	14	13	12	11	10	9	8
Name	DIV2_DQ[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV2_DQLL(0x0F35)								
Bit	7	6	5	4	3	2	1	0
Name	DIV2_DQ[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	DIV2_DQ	Quotient of DIV2. The 16 high-order bits of the data is held by DIV2_DQH and the 16 low-order bits by DIV2_DQL.						

#### 11.4.25 DIV2\_DR (0x0F36, 0x0F37)

DIV2_DRH(0x0F36)								
Bit	15	14	13	12	11	10	9	8
Name	DIV2_DR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV2_DRL(0x0F37)								
Bit	7	6	5	4	3	2	1	0
Name	DIV2_DR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	DIV2_DR	Remainder of DIV2						

#### 11.4.26 DIV3\_DA (0x0F20, 0x0F21, 0x0F22, 0x0F23)

DIV3_DAHH(0x0F20)								
Bit	31	30	29	28	27	26	25	24
Name	DIV3_DA[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV3_D AHL(0x0F21)								
Bit	23	22	21	20	19	18	17	16
Name	DIV3_DA[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV3_DALH(0x0F22)								
Bit	15	14	13	12	11	10	9	8
Name	DIV3_DA[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV3_DALL(0x0F23)								
Bit	7	6	5	4	3	2	1	0
Name	DIV3_DA[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	DIV3_DA	Dividend of DIV3. The 16 high-order bits of the data is held by DIV3_DAH and the 16 low-order bits by DIV3_DAL.						

**11.4.27 DIV3\_DB (0x0F24, 0x0F25)**

DIV3_DBH(0x0F24)								
Bit	15	14	13	12	11	10	9	8
Name	DIV3_DB[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV3_DBL(0x0F25)								
Bit	7	6	5	4	3	2	1	0
Name	DIV3_DB[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	DIV3_DB	Data register B of DIV3; Divisor of the division						

**11.4.28 DIV3\_DQ (0x0F26, 0x0F27, 0x0F28, 0x0F29)**

DIV3_DQHH(0x0F26)								
Bit	31	30	29	28	27	26	25	24
Name	DIV3_DQ[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV3_DQHL(0x0F27)								
Bit	23	22	21	20	19	18	17	16
Name	DIV3_DQ[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV3_DQLH(0x0F28)								
Bit	15	14	13	12	11	10	9	8
Name	DIV3_DQ[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV3_DQLL(0x0F29)								
Bit	7	6	5	4	3	2	1	0
Name	DIV3_DQ[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	DIV3_DQ	Quotient of DIV3. The 16 high-order bits of the data is held by DIV3_DQH and the 16 low-order bits by DIV3_DQL.						

**11.4.29 DIV3\_DR (0x0F2A, 0x0F2B)**

DIV3_DRH(0x0F2A)								
Bit	15	14	13	12	11	10	9	8
Name	DIV3_DR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DIV3_DRL(0x0F2B)								
Bit	7	6	5	4	3	2	1	0
Name	DIV3_DR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	DIV3_DR	Remainder of DIV3						

**11.4.30 SCAT0\_COS (0x0F16, 0x0F17)**

SCAT0_COSH(0x0F16)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT0_COS[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT0_COSL(0x0F17)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT0_COS[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT0_COS	COS input in SIN/COS or ATAN mode of computing unit SCAT0						

**11.4.31 SCAT0\_SIN (0x0F18, 0x0F19)**

SCAT0_SINH(0x0F18)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT0_SIN[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT0_SINL(0x0F19)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT0_SIN[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT0_SIN	SIN input in SIN/COS or ATAN mode of computing unit SCAT0						

**11.4.32 SCAT0\_THE (0x0F1A, 0x0F1B)**

SCAT0_THEH(0x0F1A)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT0_THE[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT0_THEL(0x0F1B)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT0_THE[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT0_THE	THE input in SIN/COS mode of computing unit SCAT0						

**11.4.33 SCAT0\_RES1 (0x0F1C, 0x0F1D)**

SCAT0_RES1H(0x0F1C)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT0_RES1[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

SCAT0_RES1L(0x0F1D)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT0_RES1[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT0_RES1	COS output in SIN/COS mode of computing unit SCAT0; <i>U</i> output in ATAN mode						

#### 11.4.34 SCAT0\_RES2 (0x0F1E, 0x0F1F)

SCAT0_RES2H(0x0F1E)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT0_RES2[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT0_RES2L(0x0F1F)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT0_RES2[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT0_RES2	SIN output in SIN/COS mode of computing unit SCAT0; $\theta$ output in ATAN mode						

#### 11.4.35 SCAT1\_COS (0x0F0C, 0x0F0D)

SCAT1_COSH(0x0F0C)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT1_COS[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT1_COSL(0x0F0D)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT1_COS[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT1_COS	COS input in SIN/COS or ATAN mode of computing unit SCAT1						

#### 11.4.36 SCAT1\_SIN (0x0F0E, 0x0F0F)

SCAT1_SINH(0x0F0E)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT1_SIN[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT1_SINL(0x0F0F)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT1_SIN[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT1_SIN	SIN input in SIN/COS or ATAN mode of computing unit SCAT1						

**11.4.37 SCAT1\_THE (0x0F10, 0x0F11)**

SCAT1 THEH(0x0F10)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT1_THE[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT1 THEL(0x0F11)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT1_THE[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT1_THE	THE input in SIN/COS mode of computing unit SCAT1						

**11.4.38 SCAT1\_RES1 (0x0F12, 0x0F13)**

SCAT1 RES1H(0x0F12)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT1_RES1[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT1 RES1L(0x0F13)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT1_RES1[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT1_RES1	COS output in SIN/COS mode of computing unit SCAT1; <i>U</i> output in ATAN mode						

**11.4.39 SCAT1\_RES2 (0x0F14, 0x0F15)**

SCAT1 RES2H(0x0F14)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT1_RES2[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT1 RES2L(0x0F15)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT1_RES2[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT1_RES2	SIN output in SIN/COS mode of computing unit SCAT1; <i>U</i> output in ATAN mode						

**11.4.40 SCAT2\_COS (0x0F02, 0x0F03)**

SCAT2 COSH(0x0F02)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT2_COS[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT2 COSL(0x0F03)								
Bit	7	6	5	4	3	2	1	0

Name	SCAT2_COS[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT2_COS	COS input in SIN/COS or ATAN mode of computing unit SCAT2						

#### 11.4.41 SCAT2\_SIN (0x0F04, 0x0F05)

SCAT2_SINH(0x0F04)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT2_SIN[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT2_SINL(0x0F05)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT2_SIN[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT2_SIN	SIN input in SIN/COS or ATAN mode of computing unit SCAT2						

#### 11.4.42 SCAT2\_THE (0x0F06, 0x0F07)

SCAT2_THEH(0x0F06)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT2_THE[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT2_THEL(0x0F07)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT2_THE[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT2_THE	THE input in SIN/COS mode of computing unit SCAT2						

#### 11.4.43 SCAT2\_RES1 (0x0F08, 0x0F09)

SCAT2_RES1H(0x0F08)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT2_RES1[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT2_RES1L(0x0F09)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT2_RES1[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT2_RES1	COS output in SIN/COS mode of computing unit SCAT2; U output in ATAN mode						



**11.4.44 SCAT2\_RES2 (0x0F0A, 0x0F0B)**

SCAT2_RES2H(0x0F0A)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT2_RES[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT2_RES2L(0x0F0B)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT2_RES[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT2_RES2	SIN output in SIN/COS mode of computing unit SCAT2; $\theta$ output in ATAN mode						

**11.4.45 SCAT3\_COS (0x0EF8, 0x0EF9)**

SCAT3_COSH(0x0EF8)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT3_COS[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT3_COSL(0x0EF9)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT3_COS[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT3_COS	COS input in SIN/COS or ATAN mode of computing unit SCAT3						

**11.4.46 SCAT3\_SIN (0x0EFA, 0x0EFB)**

SCAT3_SINH(0x0EFA)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT3_SIN[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT3_SINL(0x0EFB)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT3_SIN[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT3_SIN	SIN input in SIN/COS or ATAN mode of computing unit SCAT3						

**11.4.47 SCAT3\_THE (0x0EFC, 0x0EFD)**

SCAT3_THEH(0x0EFC)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT3_THE[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT3_THEL(0x0EFD)								
Bit	7	6	5	4	3	2	1	0

Name	SCAT3_THE[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT3_THE	THE input in SIN/COS mode of computing unit SCAT3						

#### 11.4.48 SCAT3\_RES1 (0x0EFE, 0x0EFF)

SCAT3_RES1H(0x0EFE)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT3_RES1[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT3_RES1L(0x0EFF)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT3_RES1[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT3_RES1	COS output in SIN/COS mode of computing unit SCAT3; <i>U</i> output in ATAN mode						

#### 11.4.49 SCAT3\_RES2 (0x0F00, 0x0F01)

SCAT3_RES2H(0x0F00)								
Bit	15	14	13	12	11	10	9	8
Name	SCAT3_RES[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
SCAT3_RES2L(0x0F01)								
Bit	7	6	5	4	3	2	1	0
Name	SCAT3_RES[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	SCAT3_RES2	SIN output in SIN/COS mode of computing unit SCAT3; $\theta$ output in ATAN mode						

#### 11.4.50 LPF0\_K (0x0FD0, 0x0FD1)

LPF0_KH(0x0FD0)								
Bit	15	14	13	12	11	10	9	8
Name	LPF0_K[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF0_KL(0x0FD1)								
Bit	7	6	5	4	3	2	1	0
Name	LPF0_K[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	LPF0_K[15:0]	K input of LPF0						

**11.4.51 LPF0\_X (0x0FD2, 0x0FD3)**

LPF0_XH(0x0FD2)								
Bit	15	14	13	12	11	10	9	8
Name	LPF0_X[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF0_XL(0x0FD3)								
Bit	7	6	5	4	3	2	1	0
Name	LPF0_X[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	LPF0_X[15:0]	X input of LPF0						

**11.4.52 LPF0\_Y (0x0FD4, 0x0FD5, 0x0FD6, 0x0FD7)**

LPF0_YHH(0x0FD4)								
Bit	31	30	29	28	27	26	25	24
Name	LPF0_Y[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF0_YHL(0x0FD5)								
Bit	23	22	21	20	19	18	17	16
Name	LPF0_Y[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF0_YLH(0x0FD6)								
Bit	15	14	13	12	11	10	9	8
Name	LPF0_Y[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF0_YLL(0x0FD7)								
Bit	7	6	5	4	3	2	1	0
Name	LPF0_Y[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	LPF0_Y[31:0]	Input and output of the register in LPF0 Input: LPF0_Y <sub>k-1</sub> Output: LPF0_Y <sub>k</sub>						

**11.4.53 LPF1\_K (0x0FC8, 0x0FC9)**

LPF1_KH(0x0FC8)								
Bit	15	14	13	12	11	10	9	8
Name	LPF1_K[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF1_KL(0x0FC9)								
Bit	7	6	5	4	3	2	1	0
Name	LPF1_K[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	LPF1_K[15:0]	K input of LPF1						

**11.4.54 LPF1\_X (0x0FCA, 0x0FCB)**

LPF1_XH(0x0FCA)								
Bit	15	14	13	12	11	10	9	8
Name	LPF1_X[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF1_XL(0x0FCB)								
Bit	7	6	5	4	3	2	1	0
Name	LPF1_X[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	LPF1_X[15:0]	X input of LPF1						

**11.4.55 LPF1\_Y (0x0FCC, 0x0FCD, 0x0FCE, 0x0FCF)**

LPF1_YHH(0x0FCC)								
Bit	31	30	29	28	27	26	25	24
Name	LPF1_Y[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF1_YHL(0x0FCD)								
Bit	23	22	21	20	19	18	17	16
Name	LPF1_Y[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF1_YLH(0x0FCE)								
Bit	15	14	13	12	11	10	9	8
Name	LPF1_Y[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF1_YLL(0x0FCF)								
Bit	7	6	5	4	3	2	1	0
Name	LPF1_Y[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	LPF1_Y[31:0]	Input and output of the register in LPF1 Input: LPF1_Y <sub>k-1</sub> Output: LPF1_Y <sub>k</sub>						

**11.4.56 LPF2\_K (0x0F78, 0x0F79)**

LPF2_KH(0x0F78)								
Bit	15	14	13	12	11	10	9	8
Name	LPF2_K[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF2_KL(0x0F79)								
Bit	7	6	5	4	3	2	1	0
Name	LPF2_K[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	LPF2_K[15:0]	K input of LPF2						

**11.4.57 LPF2\_X (0x0F7A, 0x0F7B)**

LPF2_XH(0x0F7A)								
Bit	15	14	13	12	11	10	9	8
Name	LPF2_X[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF2_XL(0x0F7B)								
Bit	7	6	5	4	3	2	1	0
Name	LPF2_X[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	LPF2_X[15:0]	X input of LPF2						

**11.4.58 LPF2\_Y (0x0F7C, 0x0F7D, 0x0F7E, 0x0F7F)**

LPF2_YHH(0x0F7C)								
Bit	31	30	29	28	27	26	25	24
Name	LPF2_Y[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF2_YHL(0x0F7D)								
Bit	23	22	21	20	19	18	17	16
Name	LPF2_Y[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF2_YLH(0x0F7E)								
Bit	15	14	13	12	11	10	9	8
Name	LPF2_Y[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF2_YLL(0x0F7F)								
Bit	7	6	5	4	3	2	1	0
Name	LPF2_Y[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	LPF2_Y[31:0]	Input and output of the register in LPF2 Input: LPF2_Y <sub>k-1</sub> Output: LPF2_Y <sub>k</sub>						

**11.4.59 LPF3\_K (0x0F70, 0x0F71)**

LPF3_KH(0x0F70)								
Bit	15	14	13	12	11	10	9	8
Name	LPF3_K[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF3_KL(0x0F71)								
Bit	7	6	5	4	3	2	1	0
Name	LPF3_K[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	LPF3_K[15:0]	K input of LPF3						

**11.4.60 LPF3\_X (0x0F72, 0x0F73)**

LPF3_XH(0x0F72)								
Bit	15	14	13	12	11	10	9	8
Name	LPF3_X[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF3_XL(0x0F73)								
Bit	7	6	5	4	3	2	1	0
Name	LPF3_X[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	LPF3_K[15:0]	X input of LPF3						

**11.4.61 LPF3\_Y (0x0F74, 0x0F75, 0x0F76, 0x0F77)**

LPF3_YHH(0x0F74)								
Bit	31	30	29	28	27	26	25	24
Name	LPF3_Y[31:24]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF3_YHL(0x0F75)								
Bit	23	22	21	20	19	18	17	16
Name	LPF3_Y[23:16]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF3_YLH(0x0F76)								
Bit	15	14	13	12	11	10	9	8
Name	LPF3_Y[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
LPF3_YLL(0x0F77)								
Bit	7	6	5	4	3	2	1	0
Name	LPF3_Y[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[31:0]	LPF3_Y[31:0]	Input and output of the register in LPF3 Input: LPF3_Y <sub>k-1</sub> Output: LPF3_Y <sub>k</sub>						

**11.4.62 PI0\_KP (0x0FB8, 0x0FB9)**

PI0_KPH(0x0FB8)								
Bit	15	14	13	12	11	10	9	8
Name	PI0_KP[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI0_KPL(0x0FB9)								
Bit	7	6	5	4	3	2	1	0
Name	PI0_KP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI0_KP	Proportional coefficient of PI0						

**11.4.63 PI0\_EK1 (0x0FBA, 0x0FBB)**

PI0_EK1H(0x0FBA)								
Bit	15	14	13	12	11	10	9	8
Name	PI0_EK1[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI0_EK1L(0x0FBB)								
Bit	7	6	5	4	3	2	1	0
Name	PI0_EK1[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI0_EK1	Previous input deviation of PI0						

**11.4.64 PI0\_EK (0x0FBC, 0x0FBD)**

PI0_EKH(0x0FBC)								
Bit	15	14	13	12	11	10	9	8
Name	PI0_EK[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI0_EKL(0x0FBD)								
Bit	7	6	5	4	3	2	1	0
Name	PI0_EK[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI0_EK	Present input deviation of PI0						

**11.4.65 PI0\_KI (0x0FBE, 0x0FBF)**

PI0_KIH(0x0FBE)								
Bit	15	14	13	12	11	10	9	8
Name	PI0_KI[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI0_KIL(0x0FBF)								
Bit	7	6	5	4	3	2	1	0
Name	PI0_KI[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI0_KI	Integral coefficient of PI0						

**11.4.66 PI0\_UKH (0x0FC0, 0x0FC1)**

PI0_UKHH(0x0FC0)								
Bit	15	14	13	12	11	10	9	8
Name	PI0_UKH[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

PI0_UKHL(0x0FC1)								
Bit	7	6	5	4	3	2	1	0
Name	PI0_UKH[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI0_UKH	16 high-order bits of PI0 output						

#### 11.4.67 PI0\_UKL (0x0FC2, 0x0FC3)

PI0_UKLH(0x0FC2)								
Bit	15	14	13	12	11	10	9	8
Name	PI0_UKL[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI0_UKLL(0x0FC3)								
Bit	7	6	5	4	3	2	1	0
Name	PI0_UKL[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI0_UKL	16 low-order bits of PI0 output						

#### 11.4.68 PI0\_UKMAX (0x0FC4, 0x0FC5)

PI0_UKMAXH(0x0FC4)								
Bit	15	14	13	12	11	10	9	8
Name	PI0_UKMAX[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI0_UKMAXL(0x0FC5)								
Bit	7	6	5	4	3	2	1	0
Name	PI0_UKMAX[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI0_UKMAX	Maximum output of PI0						

#### 11.4.69 PI0\_UKMIN (0x0FC6, 0x0FC7)

PI0_UKMINH(0x0FC6)								
Bit	15	14	13	12	11	10	9	8
Name	PI0_UKMIN[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI0_UKMINL(0x0FC7)								
Bit	7	6	5	4	3	2	1	0
Name	PI0_UKMIN[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI0_UKMIN	Minimum output of PI0						



**11.4.70 PI1\_KP (0x0FA8, 0x0FA9)**

PI1_KPH(0x0FA8)								
Bit	15	14	13	12	11	10	9	8
Name	PI1_KP[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI1_KPL(0x0FA9)								
Bit	7	6	5	4	3	2	1	0
Name	PI1_KP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI1_KP	Proportional coefficient of PI1						

**11.4.71 PI1\_EK1 (0x0FAA, 0x0FAB)**

PI1_EK1H(0x0FAA)								
Bit	15	14	13	12	11	10	9	8
Name	PI1_EK1[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI1_EK1L(0x0FAB)								
Bit	7	6	5	4	3	2	1	0
Name	PI1_EK1[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI1_EK1	Previous input deviation of PI1						

**11.4.72 PI1\_EK (0x0FAC, 0x0FAD)**

PI1_EKH(0x0FAC)								
Bit	15	14	13	12	11	10	9	8
Name	PI1_EK[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI1_EKL(0x0FAD)								
Bit	7	6	5	4	3	2	1	0
Name	PI1_EK[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI1_EK	Present input deviation of PI1						

**11.4.73 PI1\_KI(0x0FAE, 0x0FAF)**

PI1_KIH(0x0FAE)								
Bit	15	14	13	12	11	10	9	8
Name	PI1_KI[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

PI1 KIL(0x0FAF)								
Bit	7	6	5	4	3	2	1	0
Name	PI1 KI[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI1 KI	Integral coefficient of PI1						

#### 11.4.74 PI1\_UKH (0x0FB0, 0x0FB1)

PI1 UKHH(0x0FB0)								
Bit	15	14	13	12	11	10	9	8
Name	PI1 UKH[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI1 UKHL(0x0FB1)								
Bit	7	6	5	4	3	2	1	0
Name	PI1 UKH[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI1 UKH	16 high-order bits of PI1 output						

#### 11.4.75 PI1\_UKL (0x0FB2, 0x0FB3)

PI1 UKLH(0x0FB2)								
Bit	15	14	13	12	11	10	9	8
Name	PI1 UKL[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI1 UKLL(0x0FB3)								
Bit	7	6	5	4	3	2	1	0
Name	PI1 UKL[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI1 UKL	16 low-order bits of PI1 output						

#### 11.4.76 PI1\_UKMAX (0x0FB4, 0x0FB5)

PI1 UKMAXH(0x0FB4)								
Bit	15	14	13	12	11	10	9	8
Name	PI1 UKMAX[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI1 UKMAXL(0x0FB5)								
Bit	7	6	5	4	3	2	1	0
Name	PI1 UKMAX[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI1 UKMAX	Maximum output of PI1						

**11.4.77 PI1\_UKMIN (0x0FB6, 0x0FB7)**

PI1_UKMINH(0x0FB6)								
Bit	15	14	13	12	11	10	9	8
Name	PI1_UKMIN[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI1_UKMINL(0x0FB7)								
Bit	7	6	5	4	3	2	1	0
Name	PI1_UKMIN[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI1_UKMIN	Minimum output of PI1						

**11.4.78 PI2\_KP (0x0F5C, 0x0F5D)**

PI2_KPH(0x0F5C)								
Bit	15	14	13	12	11	10	9	8
Name	PI2_KP[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI2_KPL(0x0F5D)								
Bit	7	6	5	4	3	2	1	0
Name	PI2_KP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI2_KP	Proportional coefficient of PI2						

**11.4.79 PI2\_EK1 (0x0F5E, 0x0F5F)**

PI2_EK1H(0x0F5E)								
Bit	15	14	13	12	11	10	9	8
Name	PI2_EK1[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI2_EK1L(0x0F5F)								
Bit	7	6	5	4	3	2	1	0
Name	PI2_EK1[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI2_EK1	Previous input deviation of PI2						

**11.4.80 PI2\_EK (0x0F60, 0x0F61)**

PI2_EKH(0x0F60)								
Bit	15	14	13	12	11	10	9	8
Name	PI2_EK[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

PI2_EKL(0x0F61)								
Bit	7	6	5	4	3	2	1	0
Name	PI2_EK[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI2_EK	Present input deviation of PI2						

#### 11.4.81 PI2\_KI (0x0F62, 0x0F63)

PI2_KIH(0x0F62)								
Bit	15	14	13	12	11	10	9	8
Name	PI2_KI[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI2_KIL(0x0F63)								
Bit	7	6	5	4	3	2	1	0
Name	PI2_KI[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI2_KI	Integral coefficient of PI2						

#### 11.4.82 PI2\_UKH (0x0F64, 0x0F65)

PI2_UKHH(0x0F64)								
Bit	15	14	13	12	11	10	9	8
Name	PI2_UKH[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI2_UKHL(0x0F65)								
Bit	7	6	5	4	3	2	1	0
Name	PI2_UKH[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI2_UKH	16 high-order bits of PI2 output						

#### 11.4.83 PI2\_UKL (0x0F66, 0x0F67)

PI2_UKHL(0x0F66)								
Bit	15	14	13	12	11	10	9	8
Name	PI2_UKL[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI2_UKLL(0x0F67)								
Bit	7	6	5	4	3	2	1	0
Name	PI2_UKL[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI2_UKL	16 low-order bits of PI2 output						

**11.4.84 PI2\_MAX (0x0F68, 0x0F69)**

PI2_MAXH(0x0F68)								
Bit	15	14	13	12	11	10	9	8
Name	PI2_MAX[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI2_MAXL(0x0F69)								
Bit	7	6	5	4	3	2	1	0
Name	PI2_MAX[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI2_MAX	Maximum output of PI2						

**11.4.85 PI2\_MIN (0x0F6A, 0x0F6B)**

PI2_MINH(0x0F6A)								
Bit	15	14	13	12	11	10	9	8
Name	PI2_MIN[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI2_MINL(0x0F6B)								
Bit	7	6	5	4	3	2	1	0
Name	PI2_MIN[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI2_MIN	Minimum output of PI2						

**11.4.86 PI2\_KD (0x0F6C, 0x0F6D)**

PI2_KDH(0x0F6C)								
Bit	15	14	13	12	11	10	9	8
Name	PI2_KD[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI2_KDL(0x0F6D)								
Bit	7	6	5	4	3	2	1	0
Name	PI2_KD[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI2_KD	Differential coefficient of PI2						

**11.4.87 PI2\_EK2 (0x0F6E, 0x0F6F)**

PI2_EK2H(0x0F6E)								
Bit	15	14	13	12	11	10	9	8
Name	PI2_EK2[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

PI2_EK2L(0x0F6F)								
Bit	7	6	5	4	3	2	1	0
Name	PI2_EK2[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI2_EK2	Deviation before previous input deviation of PI2						

#### 11.4.88 PI3\_KP (0x0F48, 0x0F49)

PI3_KPH(0x0F48)								
Bit	15	14	13	12	11	10	9	8
Name	PI3_KP[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI3_KPL(0x0F49)								
Bit	7	6	5	4	3	2	1	0
Name	PI3_KP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI3_KP	Proportional coefficient of PI3						

#### 11.4.89 PI3\_EK1 (0x0F4A, 0x0F4B)

PI3_EK1H(0x0F4A)								
Bit	15	14	13	12	11	10	9	8
Name	PI3_EK1[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI3_EK1L(0x0F4B)								
Bit	7	6	5	4	3	2	1	0
Name	PI3_EK1[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI3_EK1	Previous input deviation of PI3						

#### 11.4.90 PI3\_EK (0x0F4C, 0x0F4D)

PI3_EKH(0x0F4C)								
Bit	15	14	13	12	11	10	9	8
Name	PI3_EK[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI3_EKL(0x0F4D)								
Bit	7	6	5	4	3	2	1	0
Name	PI3_EK[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI3_EK	Present input deviation of PI3						

**11.4.91 PI3\_KI (0x0F4E, 0x0F4F)**

PI3_KIH(0x0F4E)								
Bit	15	14	13	12	11	10	9	8
Name	PI3_KI[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI3_KIL(0x0F4F)								
Bit	7	6	5	4	3	2	1	0
Name	PI3_KI[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI3_KI	Integral coefficient of PI3						

**11.4.92 PI3\_UKH (0x0F50, 0x0F51)**

PI3_UKHH(0x0F50)								
Bit	15	14	13	12	11	10	9	8
Name	PI3_UKH[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI3_UKHL(0x0F51)								
Bit	7	6	5	4	3	2	1	0
Name	PI3_UKH[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI3_UKH	16 high-order bits of PI3 output						

**11.4.93 PI3\_UKL (0x0F52, 0x0F53)**

PI3_UKHL(0x0F52)								
Bit	15	14	13	12	11	10	9	8
Name	PI3_UKL[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI3_UKLL(0x0F53)								
Bit	7	6	5	4	3	2	1	0
Name	PI3_UKL[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI3_UKL	16 low-order bits of PI3 output						

**11.4.94 PI3\_UKMAX (0x0F54, 0x0F55)**

PI3_UKMAXH(0x0F54)								
Bit	15	14	13	12	11	10	9	8
Name	PI3_UKMAX[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

PI3 UKMAXL(0x0F55)								
Bit	7	6	5	4	3	2	1	0
Name	PI3 UKMAX[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI3 UKMAX	Maximum output of PI3						

#### 11.4.95 PI3\_UKMIN (0x0F56, 0x0F57)

PI3 UKMINH(0x0F56)								
Bit	15	14	13	12	11	10	9	8
Name	PI3 UKMIN[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI3 UKMINL(0x0F57)								
Bit	7	6	5	4	3	2	1	0
Name	PI3 UKMIN[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI3 UKMIN	Minimum output of PI3						

#### 11.4.96 PI3\_KD (0x0F58, 0x0F59)

PI3 KDH(0x0F58)								
Bit	15	14	13	12	11	10	9	8
Name	PI3 KD[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI3 KDL(0x0F59)								
Bit	7	6	5	4	3	2	1	0
Name	PI3 KD[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI3 KD	Differential coefficient of PI3						

#### 11.4.97 PI3\_EK2 (0x0F5A, 0x0F5B)

PI3 EK2H(0x0F5A)								
Bit	15	14	13	12	11	10	9	8
Name	PI3 EK2[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PI3 EK2L(0x0F5B)								
Bit	7	6	5	4	3	2	1	0
Name	PI3 EK2[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PI3 EK2	Deviation before previous input deviation of PI3						



## 12 PFC

### 12.1 PFC Operating Instructions

#### 12.1.1 PFC Introduction

Power Factor Correction (PFC) improves power efficiency and power density, optimizes voltage control the system and reduces electromagnetic compatibility and electromagnetic interference.

PFC module has the following features:

- Full-automatic hardware
- ADC automatic sampling
- Over-current protection and cycle-by-cycle current limiting

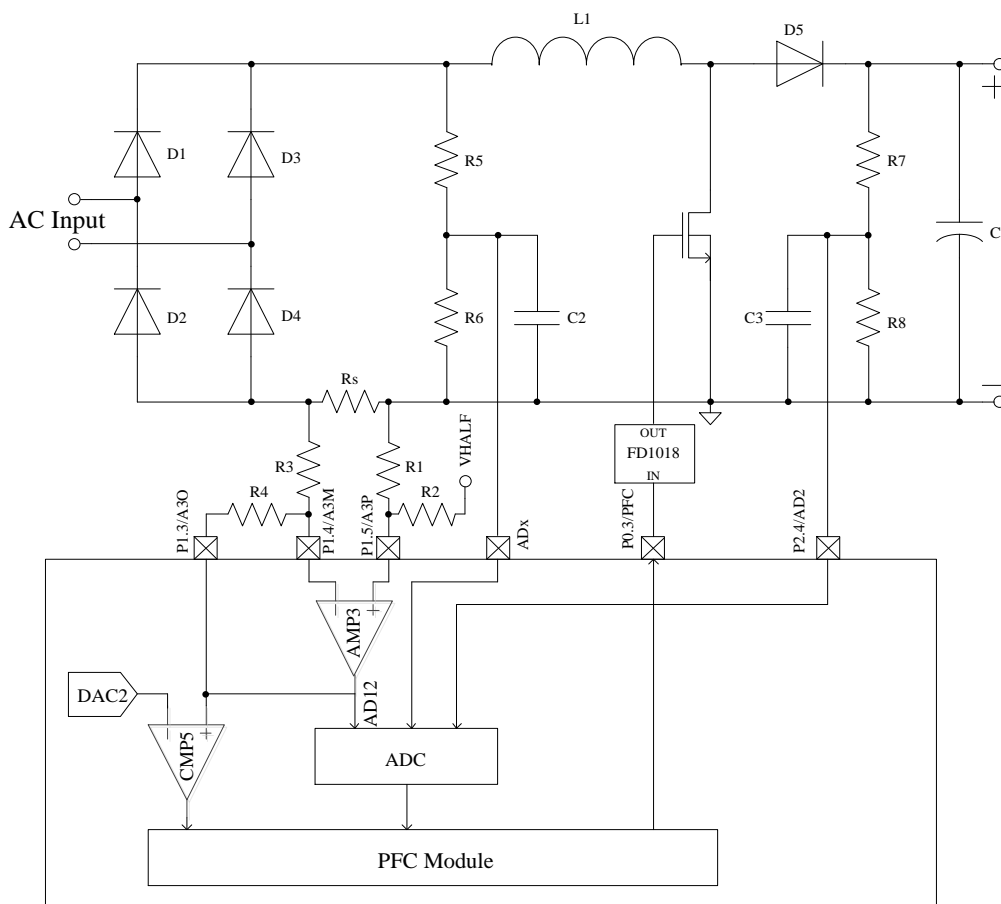


Figure 12-1 Structure Diagram of PFC Module

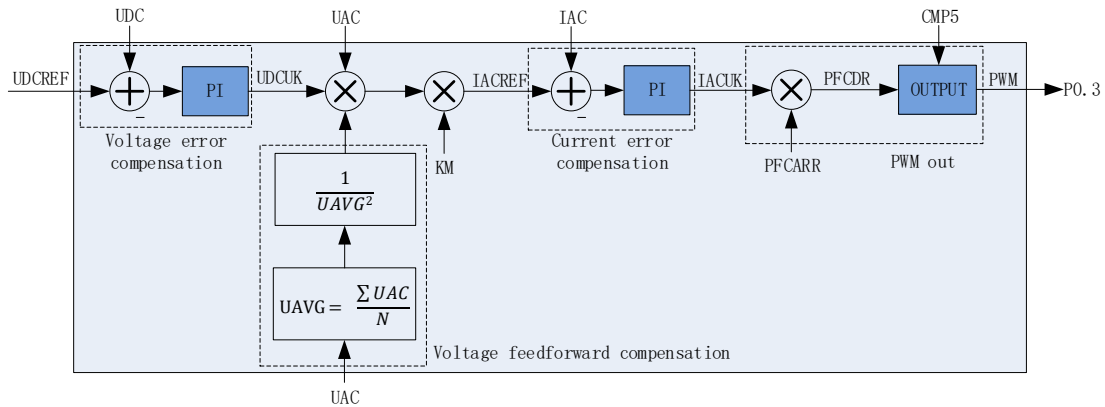


Figure 12-2 Block Diagram of PFC Module

PFC module includes voltage error compensation module, voltage feed-forward compensation module, current error compensation module and PWM output module.

### 12.1.2 Voltage Error Compensation Module

Voltage error compensation module is outer loop of the PFC module. Its input is the difference between UDCREF (user defined DCV reference) and UDC (sampled DCV by ADC), which is transmitted to PI controller to generate control output UDCUK. Outer loop frequency = Inner loop frequency /PFC\_OUTARR = 24M /PFC\_ARR /PFC\_OUTARR.

### 12.1.3 Voltage Feed-forward Compensation Module

The voltage feed-forward compensation module is mainly used to maintain a constant output power under unstable input AC voltage.

### 12.1.4 Calculation of Average Voltage

UAVG is the rectified average voltage of AC voltage UAC. The PFC module calculates UAVG by hardware automatically. This function shall be disabled for some special applications and UAVG will be calculated by software. UAVG is calculated as

$$UAVG = \frac{\sum UAC}{N}$$

where, UAC is the sampling AC voltage,  $N$  is the sampling number in time period  $T_s$ .

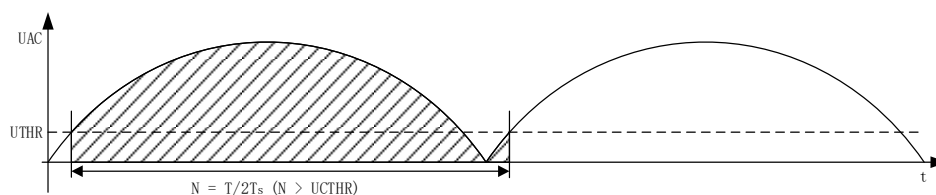


Figure 12-3 Calculation of UAVG

PFC\_CR0[UACGCDIS] is set to “0” to start the calculation of UAVG by hardware. The calculation period of UAVG is a half period of power frequency  $T$ . UTHR is the first and the last value of sampling voltage.  $T_s$  is the sampling period of UAC. UCTHR is the minimum value of UAC sampling number. When UAC in this sampling period is bigger than UTHR and the former one is smaller, this sampling period is the start or the end of a calculation period. To decrease the influence of sampling distortion, N should be adequate, larger than UCTHR.

PFC\_CR0[UACGCDIS] is set to “1” to start the calculation of UAVG by software. When PFC\_CR0[UAVGSW] = 1, the calculation period is the time between the end of last calculation period and this sampling period (PFC\_CR0[UAVGSW]). SYS\_TICK or other Timer can be used to generate a frequency for the accurate calculation of UAVG.

### 12.1.5 Current Error Compensation Module

Current error compensation module is inner loop of the PFC module. Its input is the difference between IACREF (current reference calculated by outer loop) and IAC (sampled current by ADC), which is transmitted to PI controller to generate control output IACUK. Inner loop frequency = 24MHz/PFC\_ARR.

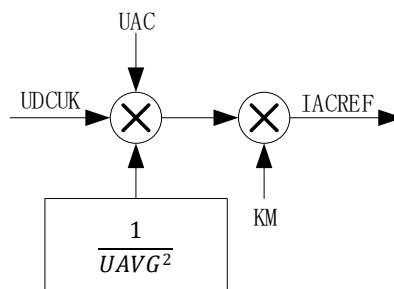


Figure 12-4 Block Diagram of the Calculation of IACREG

As shown above, multiply UDCUK, UAC, the output voltage feed-forward compensation module and constant KM, the result is IACREF.

### 12.1.6 PWM Output Module

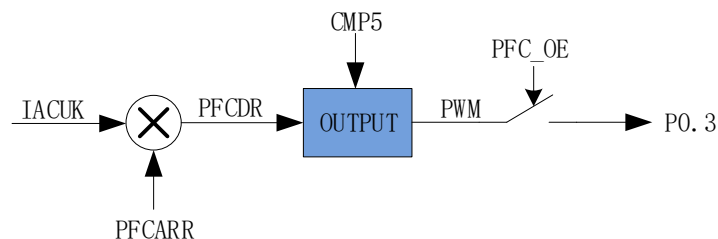


Figure 12-5 Block Diagram of PWM Output

IACUK is the duty cycle of PWM module, duty cycle =  $100\% \times \text{IACUK}/32768$ , and PWM signal is generated by comparator and output to P0.3. As shown above, PFC\_DR, the value  $\text{IACUK} \times \text{PFCARR}/32768$ , is compared with PFC timer to generate PWM signal. When  $\text{PFC\_DR} > \text{PFC\_CNTR}$ , PWM module outputs logical 1, and when  $\text{PFC\_DR} < \text{PFC\_CNTR}$ , PWM module outputs logical 0. If  $\text{PFC\_CR0}[\text{PFCOE}]$  is set to “1”, P0.3 serves as output of the PWM module.

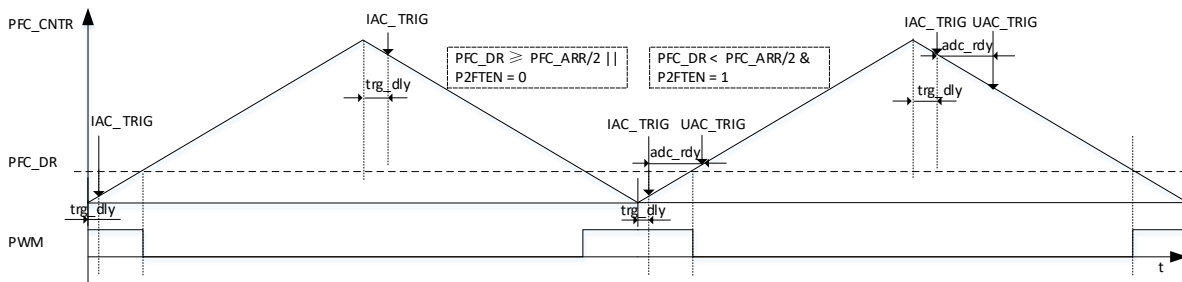


Figure 12-6 Diagram of PWM Output and IAC/UAC Sampling

### 12.1.7 Over-current Protection and Cycle-by-Cycle Current Limiting

Configuring  $\text{CMP\_CR4}[\text{CMP5EN}]$  to “1” enables CMP5 and over-current protection feature. The filter factor of CMP5 is determined by  $\text{PFC\_CR0}[\text{CPM5DIV}]$ . When the input of CMP5 is logical 1, over-current protection forces PWM module to output low voltage level. Configuring  $\text{PFC\_CR0}[\text{PFCOE}]$  to “0” disables the over-current protection feature.

### 12.1.8 UAC/IAC/UDC Sampling

#### 12.1.8.1 UDC Sampling

- UDC is sampled by FOC module every carrier period.
- Using ADC Channel-2

#### 12.1.8.2 IAC Sampling

- Sample once on overflow point or underflow point of every inner loop period
- The sampling point is determined according to  $\text{PFC\_CR2}[\text{P2FTEN}]$  and  $\text{PFC\_DR}$  (as shown in Figure 12-6). If  $\text{PFC\_CR2}[\text{P2FTEN}] = 0$  and  $\text{PFC\_DR} < \text{PFC\_ARR}/2$ , sampling is triggered when  $\text{PFC\_CNTR}$  reaches the underflow point. If  $\text{PFC\_CR2}[\text{P2FTEN}] = 1$  or  $\text{PFC\_DR} \geq \text{PFC\_ARR}/2$ , sampling is triggered when  $\text{PFC\_CNTR}$  reaches the overflow point. The time delay for sampling is configurable by  $\text{PFC\_TRGDLY}$ . The overflow point can be set at  $\text{PFC\_TRGDLY} * 8$ , and the underflow point at  $(\text{PFC\_ARR} - \text{PFC\_TRGDLY} * 8)$ .
- Using ADC Channel-6
- When  $\text{PFC\_CR0}[\text{CCHSEL}] = 0$ , a data can be written to  $\text{PFC\_CSO}$  to set IAC offset. Providing

the voltage range of ADC is 0~5V and the reference is 2.5V, then  $PFC\_CSO = 32768 \times 2.5 / 5V = 16384$  (0x4000)

### 12.1.8.3 UAC Sampling

- Set the value of  $PFC\_CR1[UACSAMSEL]$  to configure UAC sampling period, once every 1/2/4/8 inner loop periods. UAC is sampled after sampling of IAC.
- ADC Channel-5 is used by default. Set the value of  $UAC\_TRIG\_CH$  to select other ADC channels.
- When  $PFC\_CR0[CCHSEL] = 1$ , a data can be written to  $PFC\_CSO$  to set UAC offset. Providing the voltage range of ADC is 0~5V and the reference is 2.5V, then  $PFC\_CSO = 32768 \times 2.5 / 5V = 16384$  (0x4000)

## 12.2 PFC Registers

### 12.2.1 PFC\_CR2 (0x4063)

Bit	7	6	5	4	3	2	1	0
Name	PFC_BLK_MD		P2FTEN	DCLREN	PIAUTOEN	RSV	DRALEN	PFCCEN
Type	R/W	R/W	R/W	R/W	R/W	-	R/W	R/W
Reset	0	0	0	0	0	-	0	0

Bit	Name	Description
[7:6]	PFC_BLK_MD	<p>When PFC module is disabled (<math>PFC\_CR0[PFCCEN] = 0</math>), UDC_PI/IAC_PI works as a general PI controller. <math>PFC\_CR2[7]</math> serves as enable bit of the UDC_PI, and <math>PFC\_CR2[6]</math> as the IAC_PI.</p> <p>This bit is set by software to logical 1, and will be cleared by hardware at next clock. It is invalid to write 0 to this bit. When PFC module is disabled, this bit reflects busy status of the PI controller.</p> <p>0: Disable. 1: Enable.</p> <p>When PFC module is enabled (<math>PFC\_CR0[PFCCEN] = 1</math>), this bit is used to select the mask time for UAC/IAC sampling.</p> <p>00: The mask time equals the deadtime 01: The mask time is 1/2 of the deadtime 10: The mask time is twice the deadtime</p>
[5]	P2FTEN	<p>When PFC module is enabled (<math>PFC\_CR0[PFCCEN] = 1</math>), this bit and <math>PFC\_DR</math> determine trigger sampling point for IAC sampling.</p> <p>See IAC Sampling for more details.</p>
[4]	DCLREN	<p>PFC Timer Synchronization Enable</p> <p>With this bit is enabled, DRV timer is synchronized with PFC timer. When DRV timer generates an underflow event, PFC timer is cleared to “0”, so that both DRV timer and PFC timer count from 0. It is mainly used to start ADC automatic sampling when PFC/DRV timer reaches a certain value (by setting <math>PFC\_DR</math>) if PFC module is disabled.</p> <p>0: Disable 1: Enable</p>
[3]	PIAUTOEN	<p>UDC_PI/IAC_PI Automatic Enable</p> <p>When PFC module is disabled (<math>PFC\_CR0[PFCCEN] = 0</math>), UDC_PI/IAC_PI works as a general PI controller.</p> <p>With this bit enabled, the two PI controllers automatically operate once per cycle of the PFC timer.</p> <p>When <math>PFC\_CR0[PFCCEN] = 1</math>, this bit is automatically set to “1”.</p> <p>0: Disable 1: Enable</p>

[2]	RSV	Reserved
[1]	DRALEN	PFC_DR Automatic Loading Enable With this bit enabled, the underflow point of each PFC period calculates the value of PFC_DR based on the duty cycle. The formula is $IAC\_UK/32768 * PFC\_ARR$ . The result is updated to PFC_DR. When PFC_CR0[PFCEN] = 1, this bit is automatically set to "1". 0: Disable 1: Enable
[0]	PFCEN	PFC Timer Enable Bit When PFC_CR0[PFCEN] = 1, this bit is automatically set to "1". 0: Disable 1: Enable

### 12.2.2 PFC\_CR0 (0x40E0)

Bit	7	6	5	4	3	2	1	0
Name	UAVGSW	CMP5DIV		UAVGDIS	PFCOA	CCHSEL	PFCOE	PFCEN
Type	W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[7]	UAVGSW	Start UAVG Calculation Start UAVG calculation and update the result to the value of UAVG. This bit is set to "1" by software, and will be cleared by hardware at next clock. It is invalid to write 0 to this bit. 0: UAVG calculation doesn't start. 1: UAVG calculation starts.
[6:5]	CMP5DIV	Filter Period Selection of Comparator 5 When input pulse width of comparator 5 is less than the set value, it will be considered as noise and the hardware will automatically filter it out. 00: No filtering 01: 4 system clocks 10: 8 system clocks 11: 16 system clocks
[4]	UAVGDIS	UAVG Calculation by Hardware Enable When this bit is disabled, the hardware does not calculate UAVG at each power frequency period. You need to configure PFC_CR0[UAVGSW] to start UAVG calculation. UAVG calculation also starts automatically when internal timer overflows. 0: Enable 1: Disable
[3]	PFCOA	Cycle-by-cycle Current Limiting Feature Enable After comparator 5 is enabled, over-current protection feature is enabled by default. When over-current event occurs, PFC module turns off the outputs. After PFCOA is enabled, the hardware automatically restores the output after the over-current protection state is released, that is, cycle-by-cycle current limiting feature. 0: Disable 1: Enable
[2]	CCHSEL	ADC Offset Channel Selection This bit is used to select the ADC offset channel, IAC or UAC. 0: ADC offset by IAC sampling 1: ADC offset by UAC sampling
[1]	PFCOE	PFC Output Enable With this bit enabled, PWM signal generated by PFC module outputs to P0.3. 0: Disable 1: Enable
[0]	PFCEN	PFC Module Enable 0: Disable 1: Enable

**12.2.3 PFC\_CR1/UDC\_UKMINH (0x40F2)**

Bit	7	6	5	4	3	2	1	0
Name	UAC SAMSEL		UTHR	UCTHR				
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:6]	UAC SAMSEL	UAC Sampling Period Sample UAC once every x PFC periods. 00: 1 PFC period 01: 2 PFC periods 10: 4 PFC periods 11: 8 PFC periods						
[5]	UTHR	UAVG Calculation Period Threshold The sampling value, which is higher or lower than this threshold, is set as the first and the last value of a calculation period. The threshold is based on UAC_BASE. 1: $1/8 \times \text{UAC\_BASE}$ 0: $1/16 \times \text{UAC\_BASE}$						
[4:0]	UCTHR	Minimum Number of UAC Sampling Times The calculation value of UAVG is reasonable under sampling times no less than this value. The minimum sampling times = $\text{UCTHR} \times 32$						

Notes:

- PFC\_CR1 is valid only when PFC module is enabled ( $\text{PFC\_CR0}[\text{PFCEN}] = 1$ ).
- When PFC module is enabled ( $\text{PFC\_CR0}[\text{PFCEN}] = 1$ ), this register is used for PFC\_CR1 configuration. When PFC module is disabled, it is the minimum value of UDC\_PI, UDC\_UKMINH.

**12.2.4 PFC\_ADCCH (0x40E1)**

Bit	7	6	5	4	3	2	1	0																																
Name	IAC TRIG CH				UAC TRIG CH																																			
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W																																
Reset	0	1	1	0	0	1	0	1																																
Bit	Name	Description																																						
[7:4]	IAC_TRIG_CH	ADC Channel Selection for IAC Sampling Choose ADC Channel-6 when PFC is enabled, otherwise the operational amplifier is unavailable.  Table 12-1 ADC Channel Selection for IAC Sampling <table border="1" style="margin-left: 40px;"> <tr><td>0000</td><td>Channel-0</td><td>0001</td><td>Channel-1</td></tr> <tr><td>0010</td><td>Channel-2</td><td>0011</td><td>Channel-3</td></tr> <tr><td>0100</td><td>Channel-4</td><td>0101</td><td>Channel-5</td></tr> <tr><td>0110</td><td>Channel-6</td><td>0111</td><td>Channel-7</td></tr> <tr><td>1000</td><td>Channel-8</td><td>1001</td><td>Channel-9</td></tr> <tr><td>1010</td><td>Channel-10</td><td>1011</td><td>Channel-11</td></tr> <tr><td>1100</td><td>Channel-12</td><td>1101</td><td>Channel-13</td></tr> <tr><td>1110</td><td>RSV</td><td>1111</td><td>RSV</td></tr> </table>							0000	Channel-0	0001	Channel-1	0010	Channel-2	0011	Channel-3	0100	Channel-4	0101	Channel-5	0110	Channel-6	0111	Channel-7	1000	Channel-8	1001	Channel-9	1010	Channel-10	1011	Channel-11	1100	Channel-12	1101	Channel-13	1110	RSV	1111	RSV
0000	Channel-0	0001	Channel-1																																					
0010	Channel-2	0011	Channel-3																																					
0100	Channel-4	0101	Channel-5																																					
0110	Channel-6	0111	Channel-7																																					
1000	Channel-8	1001	Channel-9																																					
1010	Channel-10	1011	Channel-11																																					
1100	Channel-12	1101	Channel-13																																					
1110	RSV	1111	RSV																																					
[3:0]	UAC_TRIG_CH	ADC channel selection for UAC sampling  Table 12-2 ADC Channel Selection for UAC Sampling <table border="1" style="margin-left: 40px;"> <tr><td>0000</td><td>Channel-0</td><td>0001</td><td>Channel-1</td></tr> <tr><td>0010</td><td>Channel-2</td><td>0011</td><td>Channel-3</td></tr> <tr><td>0100</td><td>Channel-4</td><td>0101</td><td>Channel-5</td></tr> <tr><td>0110</td><td>Channel-6</td><td>0111</td><td>Channel-7</td></tr> </table>							0000	Channel-0	0001	Channel-1	0010	Channel-2	0011	Channel-3	0100	Channel-4	0101	Channel-5	0110	Channel-6	0111	Channel-7																
0000	Channel-0	0001	Channel-1																																					
0010	Channel-2	0011	Channel-3																																					
0100	Channel-4	0101	Channel-5																																					
0110	Channel-6	0111	Channel-7																																					

		1000	Channel-8	1001	Channel-9	
		1010	Channel-10	1011	Channel-11	
		1100	Channel-12	1101	Channel-13	
		1110	RSV	1111	RSV	

### 12.2.5 PFC\_CS0 (0x40E2, 0x40E3)

PFC CSOH(0x40E2)								
Bit	15	14	13	12	11	10	9	8
Name	PFC_CS0[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
PFC CSOL(0x40E3)								
Bit	7	6	5	4	3	2	1	0
Name	PFC_CS0[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PFC_CS0	IAC/UAC Sampling Reference Configure PFC_CR0[CCHSEL] to write data to PFC_CS0 set IAC/UAC ADC offset. Range: (0, 32767). MSB is always 0. Providing ADC voltage range is 0~5V, the offset is 2.5V, then $PFC\_CS0 = 32768 \times 2.5V/5V = 16384$ (0x4000).						

### 12.2.6 PFC\_ARR (0x40E4, 0x40E5)

PFC ARRH(0x40E4)								
Bit	15	14	13	12	11	10	9	8
Name	RSV				PFC_ARR[11:8]			
Type	-	-	-	-	W	W	W	W
Reset	-	-	-	-	0	0	0	0
PFC ARRL(0x40E5)								
Bit	7	6	5	4	3	2	1	0
Name	PFC_ARR[7:0]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:12]	RSV	Reserved						
[11:0]	PFC_ARR	Reload Value of PFC Timer. It configures the carrier period and operation mode (center-alignment mode). An overflow event occurs when PFC timer counts from 0 and reaches PFC_ARR, and then it counts down to 0. This register is write-only. Range: (0, 4095)						

### 12.2.7 PFC\_UAVG (0x40E4, 0x40E5)

PFC UAVGH(0x40E4)								
Bit	15	14	13	12	11	10	9	8
Name	PFC_UAVG[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
PFC UAVGL(0x40E5)								
Bit	7	6	5	4	3	2	1	0
Name	PFC_UAVG[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0



Bit	Name	Description
[15:0]	PFC_UAVG	Calculation value of average UAC in one power frequency Range: (-32768, 32767)

### 12.2.8 PFC\_DR (0x40E6, 0x40E7)

PFC DRH(0x40E6)								
Bit	15	14	13	12	11	10	9	8
Name	RSV				PFC_DR[11:8]			
Type	-	-	-	-	R/W	R/W	R/W	R/W
Reset	-	-	-	-	0	0	0	0
PFC DRL(0x40E7)								
Bit	7	6	5	4	3	2	1	0
Name	PFC_DR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:12]	RSV	Reserved						
[11:0]	PFC_DR	Comparison Value by PFC to Generate PWM Signal When PFC_DR >PFC_CNTR, PWM module outputs logical 1, and when PFC_DR <PFC_CNTR, PWM module outputs logical 0. When PFC module is enabled, PFC_DR is automatically updated by hardware. Range: (0, 4095)						

### 12.2.9 UDC\_REF (0x40E8, 0x40E9)

UDC REFH(0x40E8)								
Bit	15	14	13	12	11	10	9	8
Name	UDC_REF[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
UDC REFL(0x40E9)								
Bit	7	6	5	4	3	2	1	0
Name	UDC_REF[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	UDC_REF	This register is the UDC reference when PFC is enabled (PFC_CR0[PFCEN] = 1). This register is EK of UDC_PI when PFC is disabled (PFC_CR0[PFCEN] = 0). Range: (-32768, 32767)						

### 12.2.10 UDC\_UK (0x40EA, 0x40EB)

UDC UKH(0x40EA)								
Bit	15	14	13	12	11	10	9	8
Name	UDC_UK[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
UDC UKL(0x40EB)								
Bit	7	6	5	4	3	2	1	0
Name	UDC_UK[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	UDC_UK	Output value UK of UDCPI controller Range: (-32768, 32767)						

**12.2.11 UDC\_KP (0x40EC, 0x40ED)**

UDC KPH(0x40EC)								
Bit	15	14	13	12	11	10	9	8
Name	UDC_KP[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
UDC KPL(0x40ED)								
Bit	7	6	5	4	3	2	1	0
Name	UDC_KP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	UDC_KP	KP coefficient of UDCPI controller Range: (0, 32767). MSB is always 0. The data format is Q10.						

**12.2.12 UDC\_KI (0x40EE, 0x40EF)**

UDC KIH(0x40EE)								
Bit	15	14	13	12	11	10	9	8
Name	UDC_KI[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
UDC KIL(0x40EF)								
Bit	7	6	5	4	3	2	1	0
Name	UDC_KI[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	UDC_KI	KI coefficient of UDCPI controller Range: (0, 32767). MSB is always 0. The data format is Q15.						

**12.2.13 UDC\_UKMAX (0x40F0, 0x40F1)**

UDC UKMAXH(0x40F0)								
Bit	15	14	13	12	11	10	9	8
Name	UDC_UKMAX[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
UDC UKMAXL(0x40F1)								
Bit	7	6	5	4	3	2	1	0
Name	UDC_UKMAX[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	UDC_UKMAX	Maximum output of UDCPI controller Range (-32768, 32767)						

**12.2.14 UDC\_UKMIN (0x40F2, 0x40F3)**

UDC UKMINH(0x40F2)								
Bit	15	14	13	12	11	10	9	8
Name	UDC_UKMIN[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
UDC UKMINL(0x40F3)								

Bit	7	6	5	4	3	2	1	0
Name	UDC UKMIN[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	UDC_UKMIN	This bit is the minimum output of UDCPI controller when PFC module is disabled (PFC_CR0[PFCEN] = 0). Range (-32768, 32767) This bit is for PFC_CR1 and PFC_KM registers when PFC module is enabled (PFC_CR0[PFCEN] = 1). In this case, UDC_UKMIN is 0 by default.						

### 12.2.15 PFC\_KM (0x40F3)

Bit	7	6	5	4	3	2	1	0
Name	PFC_KM							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	PFC_KM	KM coefficient of PFC Range: (0, 255) Note: This bit is valid only when PFC module is enabled (PFC_CR0[PFCEN] = 1)						

### 12.2.16 IAC\_REF (0x40F4, 0x40F5)

IAC REFH(0x40F4)								
Bit	15	14	13	12	11	10	9	8
Name	IAC_REF[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
IAC REFL(0x40F5)								
Bit	7	6	5	4	3	2	1	0
Name	IAC_REF[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	IAC_REF	This register is the IAC reference when PFC is enabled (PFC_CR0[PFCEN] = 1). This register is EK of IAC_PI when PFC is disabled (PFC_CR0[PFCEN] = 0). Range: (-32768, 32767)						

### 12.2.17 IAC\_UK (0x40F6, 0x40F7)

IAC UKH(0x40F6)								
Bit	15	14	13	12	11	10	9	8
Name	IAC_UK[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
IAC UKL(0x40F7)								
Bit	7	6	5	4	3	2	1	0
Name	IAC_UK[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	IAC_UK	Output value UK of IACPI controller Range: (-32768, 32767)						

**12.2.18 IAC\_KP (0x40F8, 0x40F9)**

IAC KPH(0x40F8)								
Bit	15	14	13	12	11	10	9	8
Name	IAC_KP[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
IAC KPL(0x40F9)								
Bit	7	6	5	4	3	2	1	0
Name	IAC_KP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	IAC_KP	KP coefficient of IACPI controller Range: (0, 32767). MSB is always 0. The data format is Q10.						

**12.2.19 IAC\_KI (0x40FA, 0x40FB)**

IAC KIH(0x40FA)								
Bit	15	14	13	12	11	10	9	8
Name	IAC_KI[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
IAC KIL(0x40FB)								
Bit	7	6	5	4	3	2	1	0
Name	IAC_KI[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	IAC_KI	KI coefficient of IACPI controller Range: (0, 32767). MSB is always 0. The data format is Q15.						

**12.2.20 IAC\_UKMAX (0x40FC, 0x40FD)**

IAC UKMAXH(0x40FC)								
Bit	15	14	13	12	11	10	9	8
Name	IAC_UKMAX[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
IAC UKMAXL(0x40FD)								
Bit	7	6	5	4	3	2	1	0
Name	IAC_UKMAX[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	IAC_UKMAX	Maximum output of IACPI controller Range (-32768, 32767)						

**12.2.21 IAC\_UKMIN (0x40FE, 0x40FF)**

IAC UKMINH(0x40E4)								
Bit	15	14	13	12	11	10	9	8
Name	IAC_UKMIN[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
IAC UKMINL(0x40FF)								

Bit	7	6	5	4	3	2	1	0
Name	IAC_UKMIN[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	IAC_UKMIN	This bit is the minimum output of IACPI controller when PFC module is disabled (PFC_CR0[PFCEN] = 0). Range (-32768, 32767) This bit is for PFC_TRGDLY and PFC_OUTARR registers when PFC module is enabled (PFC_CR0[PFCEN] = 1). In this case, IAC_UKMIN is 0 by default.						

### 12.2.22 PFC\_TRGDLY/PFC\_OUTARR (0x40FE, 0x40FF)

PFC_OUTARRH(0x40FE)								
Bit	15	14	13	12	11	10	9	8
Name	PFC_TRGDLY				PFC_OUTARR[11:8]			
Type	-	-	-	-	R/W	R/W	R/W	R/W
Reset	-	-	-	0	0	0	0	0
PFC_OUTARRL(0x40FF)								
Bit	7	6	5	4	3	2	1	0
Name	PFC_OUTARR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:12]	PFC_TRGDLY	ADC Sampling Delay of IAC Channel According to the MCU clock, 24MHz (41.67ns), if PFC_TRGDLY = 5, the sampling time is delayed for $41.67\text{ns} \times 2 \times 5 = 416.7\text{ns}$ . Range (0, 15) Note: This bit is valid only when PFC module is enabled (PFC_CR0[PFCEN] = 1).						
[11:0]	PFC_OUTARR	Period of PFC outer loop This bit configures the period of PFC outer loop, i.e., UDCPI controller. Period of outer loop = Period of inner loop / PFC_OUTARR = 24M / PFC_ARR / PFC_OUTARR According to the MCU clock, 24MHz (41.67ns), if PFC_ARR = 150, PFC_OUTARR = 200, the period of inner loop = $24000000 / 2 / PFC_ARR = 80000\text{Hz}$ ; the period of outer loop = $80000 / PFC_OUTARR = 400\text{Hz}$ . Range: (0, 2047) Note: This bit is valid only when PFC module is enabled (PFC_CR0[PFCEN] = 1).						

### 12.2.23 PFC\_UAC (0x409A, 0x409B)

PFC_UACH(0x409A)								
Bit	15	14	13	12	11	10	9	8
Name	PFC_UAC[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
PFC_UACL(0x409B)								
Bit	7	6	5	4	3	2	1	0
Name	PFC_UAC[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PFC_UAC	Sampling threshold triggered by ADC voltage						

**12.2.24 PFC\_IAC (0x409C, 0x409D)**

PFC_IACH(0x409C)								
Bit	15	14	13	12	11	10	9	8
Name	IAC[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
PFC_IACL(0x409D)								
Bit	7	6	5	4	3	2	1	0
Name	PFC_IAC[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	PFC_IAC	Sampling threshold triggered by ADC current						

## 13 FOC

### 13.1 FOC Overview

#### 13.1.1 FOC Introduction

The FOC module is used in sensorless and sensed FOC motor drive applications and SVPWM-based motor control applications. When  $DRV\_CR[FOC\_EN] = 0$ , FOC module is inactivated and FOC clock stops. The relevant FOC registers are forced into the reset state and cannot be written.

The FOC module consists of angle estimator, PI controller, coordinate transform module, current sampling module and PWM output module. The angle estimator uses the sampling motor current to estimate the rotor position and implement sensorless FOC-based motor control. MCU can also process the signals from the position sensor to implement sensed FOC-based control.

- Sensorless FOC: Angle for coordinate transformation is obtained by angle estimator, and the motor speed is estimated for speed closed-loop control.
- Sensor-based FOC: FOC module provides the angle input interface. MCU samples position sensor signals and calculates electrical angle of the motor. Software sends the result to FOC module for coordinate transformation.

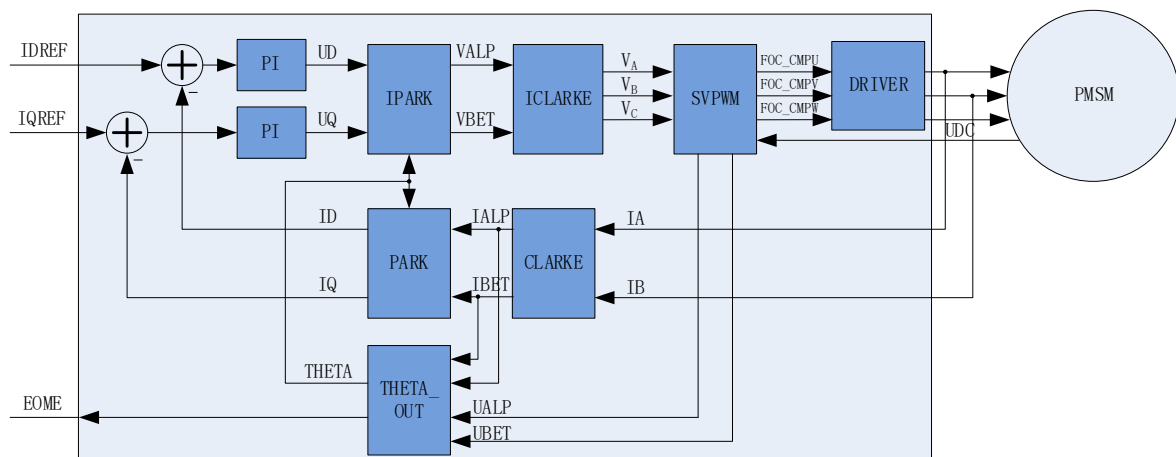


Figure 13-1 FOC Block Diagram

#### 13.1.2 Reference Voltage (VREF) Input

The current loop of FOC module uses the d-axis current reference value  $FOC\_IDREF$  and the q-axis current reference value  $FOC\_IQREF$  as the reference, and uses the d-axis current sampling value  $FOC\_ID$  and the q-axis current sampling value  $FOC\_IQ$  as the feedback. FOC module outputs real-time estimated motor speed  $FOC\_EOME$ . MCU can use  $FOC\_EOME$  as the feedback to build speed loop and send the output of speed loop to  $FOC\_IQREF$  to implement the speed-current dual closed loop control.

### 13.1.3 PI Controller

FOC module integrates two PI controllers:

1. Flux control: PI controller of d-axis current, with current reference FOC\_IDREF minus feedback current FOC\_ID as the error input, proportional coefficient FOC\_DQKP and the integral coefficient FOC\_DQKI for adjustment of PI performance, and FOC\_DMAX and FOC\_DMIN for limiting of the output amplitude. The output is voltage reference of d-axis FOC\_UD;
2. Torque control: PI controller of q-axis current, with current reference FOC\_IQREF minus feedback current FOC\_IQ as the error input, proportional coefficient FOC\_DQKP and the integral coefficient FOC\_DQKI for adjustment of PI performance, and FOC\_QMAX and FOC\_QMIN for limiting of the output amplitude. The output is voltage reference of q-axis FOC\_UQ.

### 13.1.4 Coordinate Transformation

#### 13.1.4.1 Inverse Park Transformation

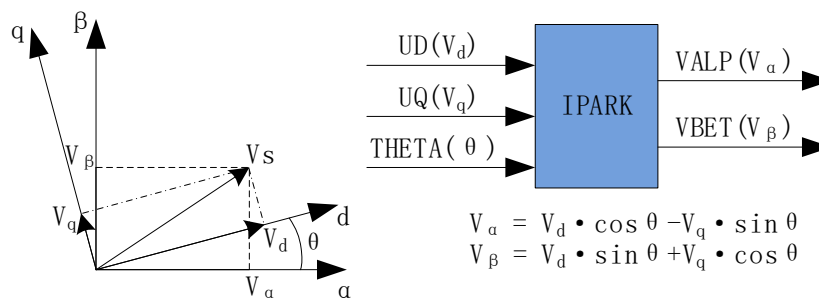


Figure 13-2 Invers Park Transformation

Inverse Park transformation is used to transform two voltage vectors obtained by PI controller, FOC\_UD and FOC\_UQ, from dq-axis coordinate to  $\alpha\beta$ -axis coordinate.



### 13.1.4.2 Inverse Clarke Transformation

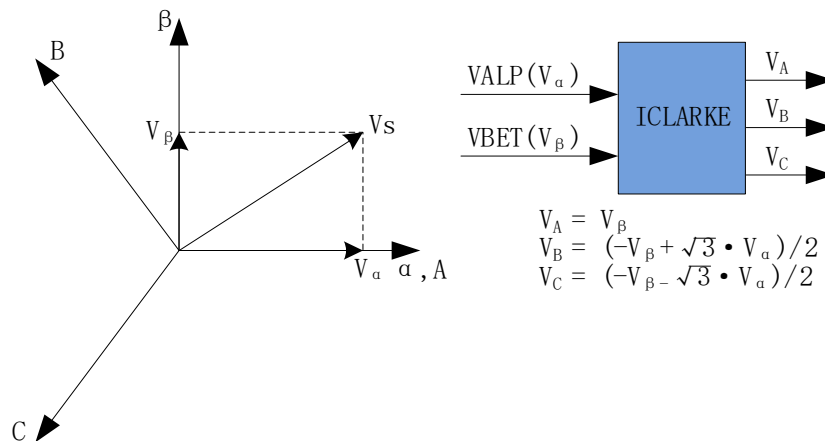


Figure 13-3 Inverse Clarke Transformation

Inverse Clarke transformation is used to transform voltage vector from  $\alpha\beta$ -axis coordinate to 3-phase stationary coordinate.

### 13.1.4.3 Clarke Transformation

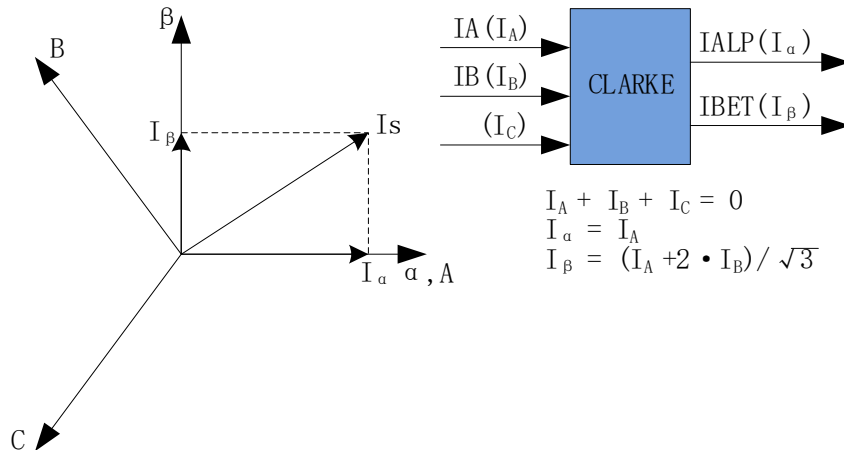


Figure 13-4 Clarke Transform

Clarke transformation is used to transform the sampled current from 3-phase stationary coordinate to  $\alpha\beta$ -axis coordinate.

### 13.1.4.4 Park Transformation

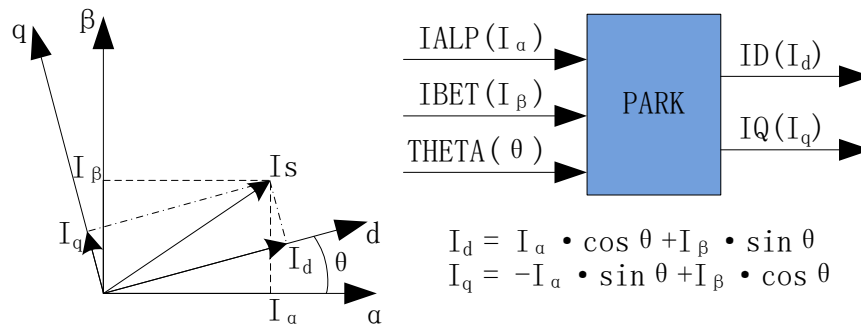


Figure 13-5 Park Transform

Park transformation is used to transform the current vectors, obtained after Clarke transformation, from  $\alpha\beta$ -axis coordinate to dq-axis coordinate to get the sampled dq-axis current FOC\_\_ID and FOC\_\_IQ.

### 13.1.5 SVPWM

SVPWM algorithm is an important part of FOC. The main idea is to obtain quasi-circular rotating magnetic field by switching the inverter space voltage vectors. This method decreases harmonic components of the phase current, harmonic losses of the motor and torque ripple, and achieves high voltage utilization.

SVPWM generates pulse-width modulation signals for the 3-phase motor voltage control, whose process can be reduced to a few simple equations. Since high side and low side of the inverter cannot be turned on simultaneously, there are two states for a phase, i.e., phase connected to bus voltage (represented by 1) or phase connected to ground (represented by 0). Therefore, voltage vector output of THE inverter has a total of  $2^3 = 8$  possible states.  $X_C X_B X_A$  represents the voltage vectors, where  $X_C$  represents the state of C-phase,  $X_B$  represents the state of B-phase and  $X_A$  represents the state of A-phase. For example, “100” represents the state that C-phase voltage is connected to bus voltage and A, B-phases are connected to ground. When the states of 3-phase are all 1 or 0, there is no voltage drop between two phases and the state is called inactive state or zero voltage vector. The other 6 states which have voltage output are active voltage vectors with an adjacent state rotation offset of 60 degrees.

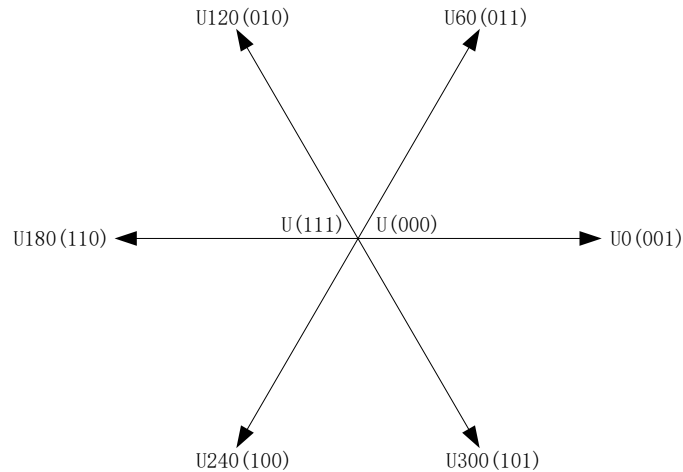


Figure 13-6 SVPWM Voltage Vector

SVPWM uses the sum of two adjacent vectors to generate any voltage vector located in the voltage vector space. As shown in Figure 13-7,  $U_{OUT}$  is the desired vector and it is in the sector between  $U_{60}$  and  $U_0$ . Based on the principle of equal impulse, the effect,  $U_0$  applied  $2 \cdot T_1$  time and  $U_{60}$  applied  $2 \cdot T_2$  time, is equivalent to the  $U_{OUT}$ . The rest of time ( $T_0$ ) is applied by zero voltage vector.

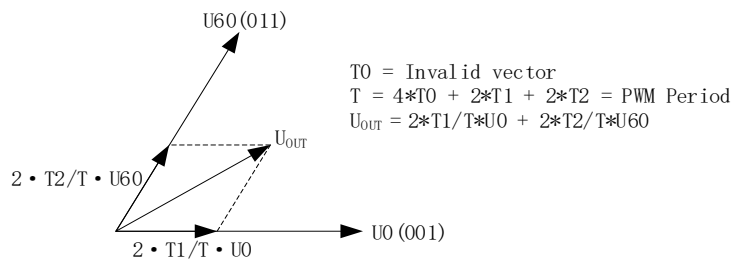


Figure 13-7 SVPWM Voltage Vector Synthesis

Table 13-1 States of SVPWM Inverter

Phase C	Phase B	Phase A	$U_{ALP}$	$U_{BET}$	Vector
0	0	0	0	0	000
0	0	1	$2/3 \cdot U_{DC}$	0	001
0	1	1	$1/3 \cdot U_{DC}$	$1/3 \cdot U_{DC}$	011
0	1	0	$-1/3 \cdot U_{DC}$	$1/3 \cdot U_{DC}$	010
1	1	0	$-2/3 \cdot U_{DC}$	0	110
1	0	0	$-1/3 \cdot U_{DC}$	$-1/3 \cdot U_{DC}$	100
1	0	1	$1/3 \cdot U_{DC}$	$-1/3 \cdot U_{DC}$	101
1	1	1	0	0	111

### 13.1.5.1 Continuous SVPWM

In single-shunt current sampling mode, continuous SVPWM is always used. In dual/triple-shunt current sampling mode, FOC\_CR2[F5SEG] is set to “0” to select continuous SVPWM as the output mode.

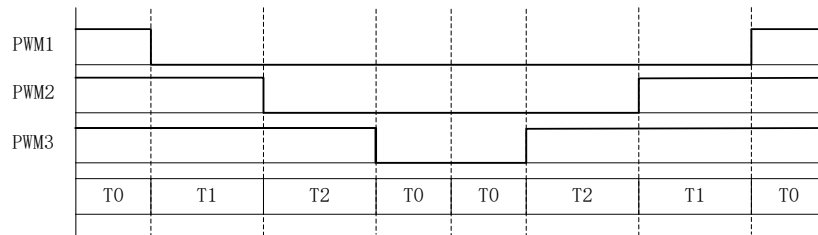


Figure 13-8 Output Level of Continuous SVPWM

### 13.1.5.2 Discontinuous SVPWM

Discontinuous SVPWM is available in dual/triple-shunt current sampling mode. FOC\_CR2[F5SEG] is set to “1” to activate this mode.

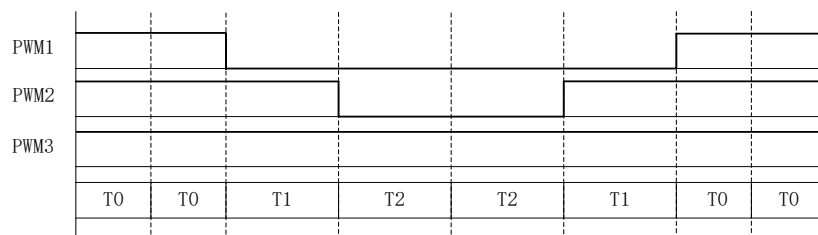


Figure 13-9 Output Level of Discontinuous SVPWM

### 13.1.6 Overmodulation

Overmodulation is available in single/dual/triple-shunt current sampling mode. Configuring FOC\_CR1[OVMDL] = 1 enables overmodulation feature. The FOC\_UD, FOC\_UQ, related limit amplitudes and voltage output are multiplied by 1.15 in this mode.

### 13.1.7 Deadtime Compensation

Deadtime compensation is available in dual/triple-shunt current sampling mode. The compensation value of deadtime is configured by FOC\_TSMIN. This mode improves the quality of phase current at low speed.

### 13.1.8 Current and Voltage Sampling

In FOC mode, bus voltage and phase current are sampled by hardware automatically. Before the FOC module operates, ADC and operational amplifier shall be enabled and the corresponding control registers be configured. No configuration is required for ADC channel and mode. Single/dual/triple-shunt current sampling mode is selected by setting FOC\_CR1[CSM]. In single-shunt current sampling mode, ADC channel 4 is the default sampling channel of the bus current (itrip). In dual-shunt current sampling mode, ADC channel 0 and channel 1 are the default sampling channels of A-phase current (ia) and B-phase current (ib) respectively. In triple-shunt current sampling mode, ADC channel 0, channel 1 and channel 4 are the default sampling channels of ia, ib and C-phase current (ic) respectively. Channel 2 can be selected for bus voltage

sampling.

### 13.1.8.1 Single-shunt Current Sampling Mode

FOC\_CR1[CSM] is set to “00” to select the single-shunt current sampling mode. In this mode, FOC module samples *itrip* (channel 4) twice during DRV timer counting-up operation, and samples bus voltage during DRV timer counting-down operation and after FOC module completes the calculation.

Since deadtime affects the accuracy of current sampling, FOC module samples within T1' and T2', which is the applied time of active voltage vector with deadtime removed. FOC\_TRGDLY is the register which advance or delay the current sampling time, and this register shall be configured reasonably to ensure sampling is completed within T1' and T2'. For example, if FOC\_TRGDLY = 5, the sampling time is delayed by  $5 * T = 208\text{ns}$ ; and if FOC\_TRGDLY = 0xFB(-5), the sampling time is advanced by  $5 * T = 208\text{ns}$ .

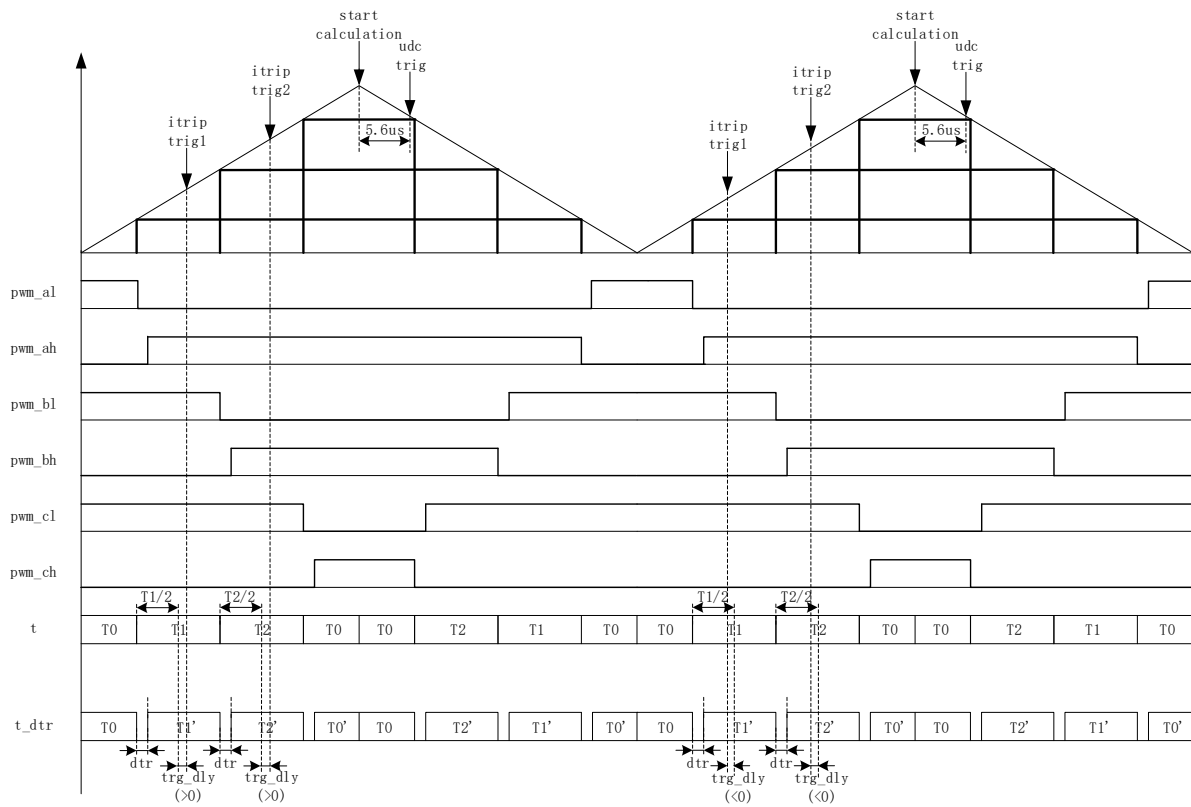


Figure 13-10 Single-shunt Current Sampling Timing

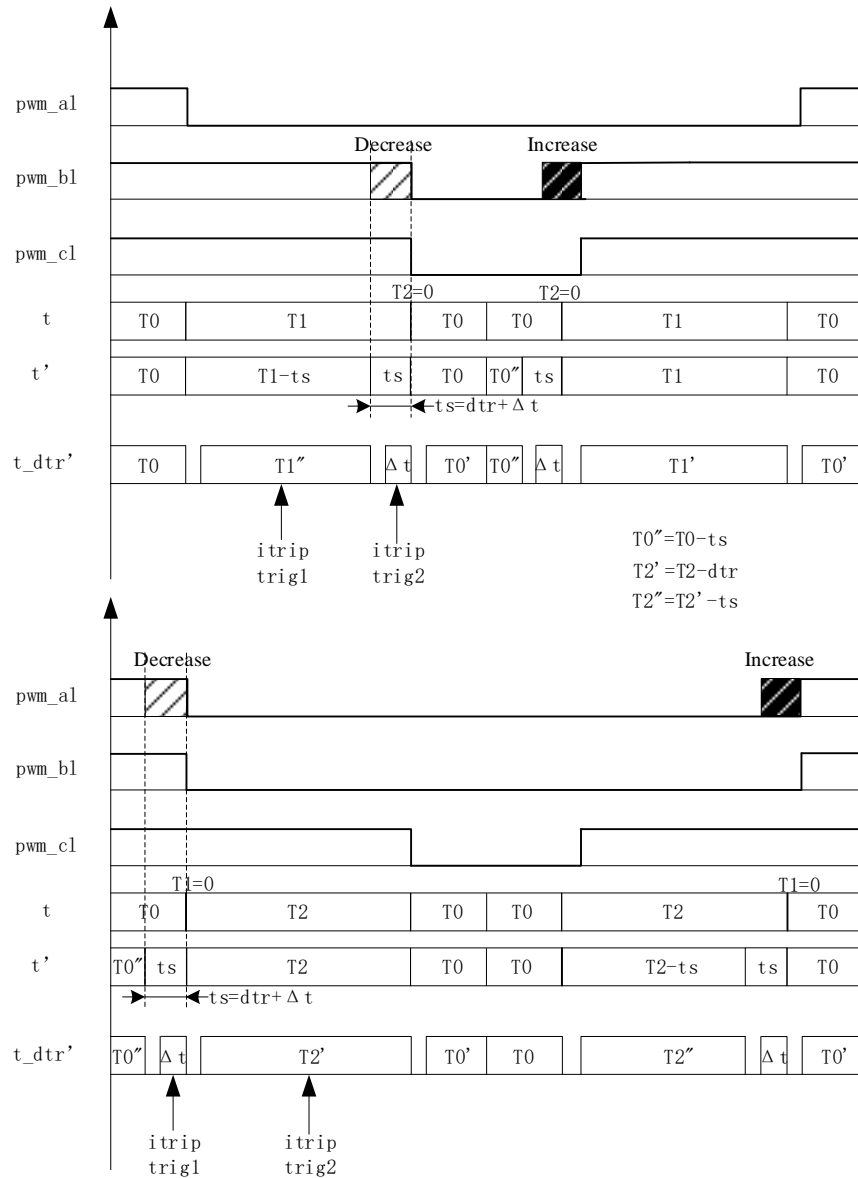


Figure 13-11 Single-shunt Current Sampling Time Compensation

The time of single-shunt current sampling window may be not enough to sample the current in low modulation index and sector switching area. PWM waveform shall be adjusted to ensure the minimum sampling window required in the case. FOC\_TSMIN (FOC\_TSMIN = minimum sampling window + deadtime) is used to configure the compensation value of deadtime, and FOC module adjusts the PWM waveform automatically.

### 13.1.8.2 Dual/Triple-shunt Current Sampling Mode

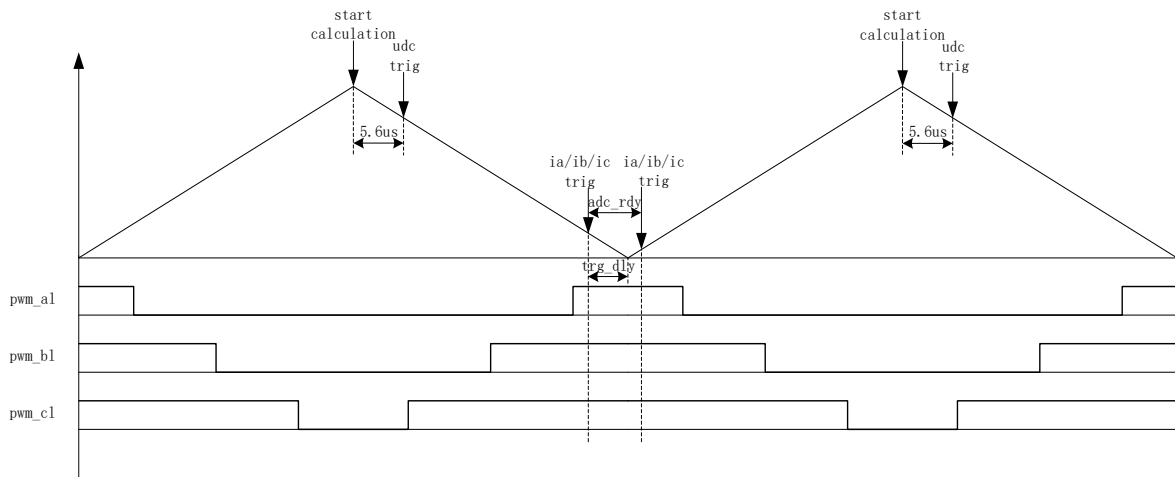


Figure 13-12 Dual/Triple-shunt Sequential Current Sampling Mode

FOC\_CR1[CSM] is set to “10/11” and FOC\_CR2[DSS] to “0” to select dual/triple-shunt sequential current sampling mode. In triple-shunt sequential current sampling mode, FOC\_TRGDLY is used to configure the sampling time of a phase current (ia/ib/ic is determined according to the sector), and other phases are sampled at the end of previous sampling. In dual-shunt sequential current sampling mode, FOC\_TRGDLY is used to configure the sampling time of ia, and ib is sampled at the end of ia sampling. TRG\_DLY shall be configured reasonably to ensure current sampling time is within zero voltage vector (000). For example, when FOC\_TRGDLY = 0xB2 and FOC timer counts down, ia/ib/ic is sampled at  $50 \cdot T = 2.08\mu\text{s}$  before an underflow event, and then the other phases of ia/ib/ic are sampled.

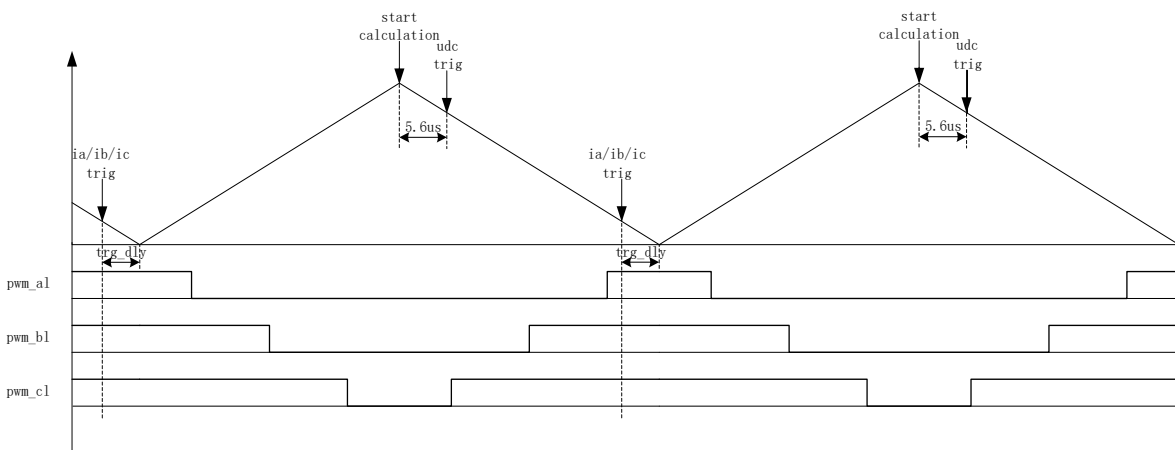


Figure 13-13 Dual/Triple-shunt Alternate Current Sampling Mode

FOC\_CR1[CSM] is set to “10/11” and FOC\_CR2[DSS] to “1” to select dual/triple-shunt alternating current sampling mode. In this mode, FOC module performs calculation in every PWM cycle. However, only one phase current is sampled at each PWM cycle (ia/ib/ic is determined according to the sector). The first

carrier cycle samples one phase of the ia/ib/ic, and the second carrier cycle samples the current of the other phase, so as to alternately sample the current of two phases in three phases. FOC\_TRGDLY is used to configure the sampling time of ia (channel 0), ib (channel 1) and ic (channel 4). TRG\_DLY shall be configured reasonably to ensure sampling time for the ia/ib/ic current is within zero voltage vector (000). For example, when FOC\_TRGDLY = 0xB2 and FOC timer counts-down, phase current is sampled at  $50 * T = 2.08\mu s$  before an underflow event.

In dual/triple-shunt current sampling mode, bus voltage is sampled when driver timer is down-counting and FOC module completes the calculation.

### 13.1.8.3 Current Sampling Offset

The current sampling offset voltage shall be added to sample full range of current due to the existence of the positive and negative phase current. When phase current is 0, ADC result is the offset value. ADC result minus this value, 0x4000 default, is the sampling current. Since ADC reference voltage and hardware are nonideal, there is a deviation between the default value and the real value. Therefore, it is necessary to calibrate the offset. The calibration procedure is as follows. When there is no current in three phases, MCU starts to sample the corresponding channel several times, averages all the sampled value, and writes the averaged value to FOC\_CSO. Providing ADC sampling range is 0 ~ 5V and the offset is 2.5V,  $FOC\_CSO = 2.5V/5V * 32768 = 16384$  (0x4000).

- When FOC\_CHC[CSOC] = 00/11, FOC\_CSO is written to modify the offset of itrip and ic.
- When FOC\_CHC[CSOC] = 01, FOC\_CSO is written to modify the offset of ia.
- When FOC\_CHC[CSOC] = 10, FOC\_CSO is written to modify the offset of ib.

### 13.1.8.4 Angle Mode

Angle module includes angle estimation module, ramping module and estimated angle smooth switching module. The sources of angle are as follows:

- Forced ramping angle
- Forced pulling angle
- Estimated angle of estimator
- Forced angle of estimator

Table 13-2 Sources of Angle

FOC_CRI[RFAE]	FOC_CRI[ANGM]	FOC_CRI[EFAE]	Source
1	X	X	Forced ramping angle
0	0	X	Forced pulling angle
0	1	0	Estimated angle of estimator
0	1	1	omega > FOC_EFREQMIN: Estimated angle of estimator omega < FOC_EFREQMIN: Forced angle of estimator



### 13.1.8.5 Forced Ramping Angle

Forced ramping angle is controlled by angle FOC\_\_THETA, speed FOC\_\_RTHESTEP, acceleration FOC\_RTHEACC and ramping counter FOC\_RTHECNT. The formula is:

$$\text{FOC\_RTHESTEP (32-bit)} = \text{FOC\_RTHESTEP (32-bit)} + \text{FOC\_RTHEACC (16 low-order bits)}$$

$$\text{THETA\_OL (16-bit)} = \text{THETA\_OL (16-bit)} + \text{FOC\_RTHESTEP (16 high-order bits)}$$

Where, THETA\_OL is an internal variable of the chip. In forced ramping angle mode, THETA\_OL is written to FOC\_THETA as the used angle. If the software writes a value to FOC\_\_THETA, this value is written to THETA\_OL as well.

Forced ramping angle has the highest priority. Configuring FOC\_CR1[RFAE] to “1” enables the ramping feature. Ramping module makes a ramping operation in every PWM cycle and the counter is added by 1. When the value of the counter reaches the set value by FOC\_RTHECNT, FOC\_CR1[RFAE] is cleared by hardware, and then the ramping is completed. Thereafter, according to the value of FOC\_CR1[ANGM], the angle comes from estimator (FOC\_CR1[ANGM] = 1) or forced pulling angle (FOC\_CR1[ANGM] = 0).

### 13.1.8.6 Forced Pulling Angle

Forced pulling angle is controlled by angle FOC\_THETA and speed FOC\_RTHESTEP. The formula is:

$$\text{THETA\_OL (16-bit)} = \text{THETA\_OL (16-bit)} + \text{FOC\_RTHESTEP (16 high-order bits)}$$

Where, THETA\_OL is an internal variable of the chip. In forced pulling angle mode, THETA\_OL is written to FOC\_THETA as the used angle. If the software writes a value to FOC\_\_THETA, this value is written to THETA\_OL as well.

- When FOC\_CR1[RFAE] is set to “1” and FOC\_CR1[ANGM] to “0”, MCU switches to forced pulling angle mode after forced ramping angle mode. The speed is the cumulative result after ramp force angle mode. This mode implements a forced uniform speed control.
- When FOC\_CR1[RFAE] is set to “0” and FOC\_CR1[ANGM] to “0”, the angle is the forced pulling angle and the speed FOC\_\_RTHESTEP is the initial speed written by software. Configuring FOC\_\_RTHESTEP to “0” enables the pre-position feature. The sensor-based FOC is implemented after the motor speed is set with FOC\_RTHESTEP. (Principle of Sensor-based FOC: The angle and speed are written to FOC\_\_THETA and FOC\_\_RTHESTEP by software, and FOC module generates an angle in each PWM cycle based on the written values.)

### 13.1.8.7 Estimator Output Angle

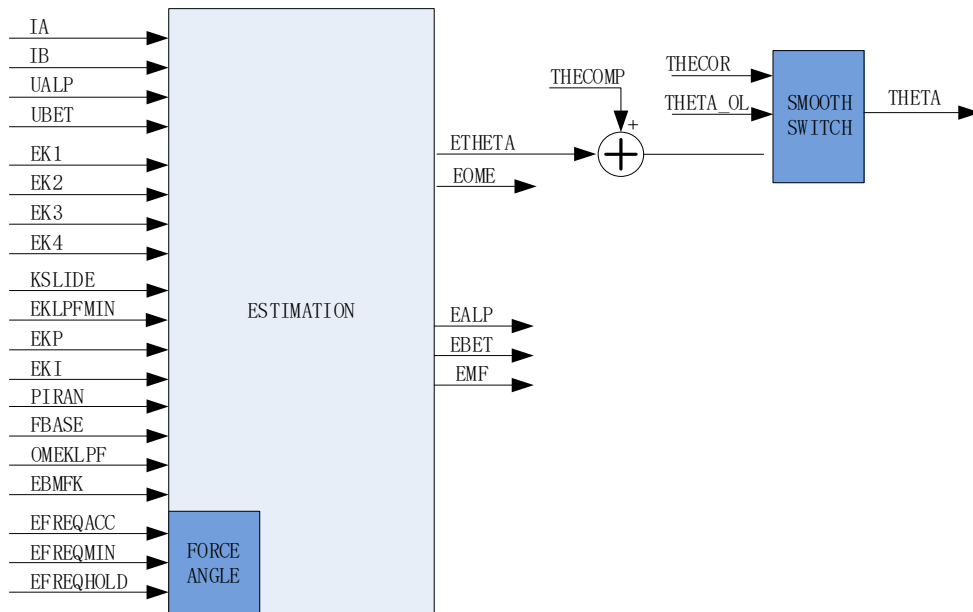


Figure 13-14 Schematic Block Diagram of Estimator

#### 13.1.8.7.1 Estimated Angle of Estimator

The estimator builds the motor model based on the motor parameters and control parameters, and outputs the estimated angle based on the sampled current and voltage. The estimator works in PLL mode or SMO mode by configuring the FOC\_CR2[ESEL] bit.

#### 13.1.8.7.2 Forced Angle of Estimator

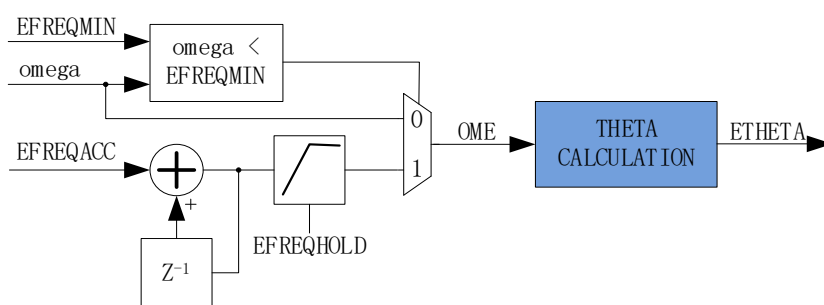


Figure 13-15 Schematic Diagram of Forced Angle of Estimator

This feature is similar to the ramping feature. Due to the low speed at motor starting process, there may be a deviation in angle and speed estimation with the small effective signal, resulting in startup failure. In this case, the estimator outputs the forced angle to ensure the motor start normally.

The forced angle feature of the estimator is enabled when FOC\_CR1[RFAE] is set to “0”, FOC\_CR1[ANGM] to “1” and FOC\_CR1[EFAE] to “1”. As shown in Figure 13-15, the estimator compares

the value of real-time estimated speed ( $\omega$ ) and FOC\_EFREQMIN to determine  $\omega$  or forced speed (FOC\_ETHERA) as the used speed (OME). When  $\omega < \text{FOC\_EFREQMIN}$ , the forced speed is selected as OME. The forced speed starts with 0 and increases by FOC\_EFREQACC in each PWM cycle, with the maximum value FOC\_EFREQHOLD. When  $\omega \geq \text{FOC\_EFREQMIN}$ ,  $\omega$  is selected as OME.

Estimated speed of the estimator FOC\_EOME is the low-pass filtering result of OME with the coefficient set by FOC\_OMEKLPF.

### 13.1.8.7.3 Angle Smooth Switching

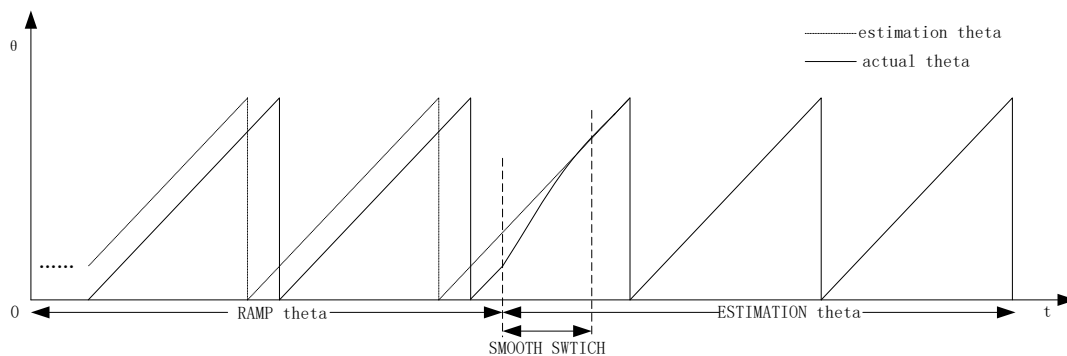


Figure 13-16 Angle Smooth Switching Curve

When FOC\_CR1[RFAE] is set to “1” and FOC\_CR1[ANGM] to “1”, the motor starts with ramping feature, and it switches to estimator angle mode after the ramping. However, there is usually a deviation between the estimated angle (FOC\_ETHERA) and the forced ramping angle (THETA\_OL). If the angle is switched from forced ramping angle to estimated angle directly, motor jitter may occur due to such a sudden change. To deal with this problem, a smooth switching is preferred.

After ramping, if the deviation between FOC\_ETHERA and THETA\_OL is less than or equal to FOC\_THECOR, FOC\_ETHERA is selected as the output angle. But if the deviation is larger than FOC\_THECOR, THETA\_OL is modified smoothly with the step of FOC\_THECOR at every PWM cycle until it is close to FOC\_ETHERA. After the deviation is less than THECOR, FOC\_ETHERA is selected as the output angle.

### 13.1.8.7.4 Angle Compensation

Angle compensation value FOC\_THECOMP is used to compensate for the estimated angle FOC\_ETHERA. If FOC\_THECOMP is negative, the lag angle is compensated; if it is positive, the lead angle is compensated.

## 13.1.9 Motor Real-time Parameters

MCU monitors the state of motor using the following real time variables provided by FOC module:

- Used angle FOC\_\_THETA
- Estimated angle FOC\_\_ETHETA, Estimated speed FOC\_\_EOME
- d-axis voltage FOC\_\_UD, q-axis voltage FOC\_\_UQ
- d-axis current FOC\_\_ID, q-axis current FOC\_\_IQ
- $\alpha$ -axis voltage FOC\_\_VALP,  $\beta$ -axis voltage FOC\_\_VBET
- Bus voltage FOC\_\_UDCFLT
- Phase current FOC\_\_IA, FOC\_\_IB, FOC\_\_IC and maximum phase current FOC\_\_IAMAX, FOC\_\_IBMAX, FOC\_\_ICMAX
- $\alpha$ -axis current (equal to FOC\_\_IA),  $\beta$ -axis current FOC\_\_IBET
- $\alpha$ -axis BEMF FOC\_\_EALP,  $\beta$ -axis BEMF FOC\_\_EBET
- Magnitude of BEMF FOC\_\_EMF
- Motor power FOC\_\_POW

### 13.1.9.1 Tailwind/headwind Detection

FOC module provides tailwind/headwind detection feature. FOC module starts to operate when FOC\_\_CR0 [ESCMS] is set to “1”, FOC\_\_IDREF to “0” and FOC\_\_IQREF to “0”. Motor’s rotor state is detected by FOC\_\_ETHETA and FOC\_\_EOME. If FOC\_\_ETHETA decreases or FOC\_\_EOME is a negative value, the motor rotates in the headwind state and it is necessary to brake first and then start the motor with ramping forced angle mode. If FOC\_\_ETHETA increases or FOC\_\_EOME is a positive value, the motor rotates in the tailwind state and can be started using estimated angle directly.

### 13.1.9.2 BEMF Detection

Estimator estimates  $\alpha$ -axis BEMF FOC\_\_EALP and  $\beta$ -axis BEMF FOC\_\_EBET with the motor parameters, and calculates the magnitude of FOC\_\_EMF, which implements protection features, such as motor lock protection, phase loss protection, etc.

### 13.1.9.3 Motor Power

FOC module calculates motor power based on the sampling current, modulation index of SVPWM and bus voltage.

### 13.1.10 FG Output Generation

FG signal is generated by FOC module and Timer4. FOC module calculates an FG result based on frequency base  $f_{base}$ , low-pass filtered speed FOC\_\_EOMELPF and FG coefficient FOC\_\_KFG in every PWM cycle. The result is updated to TIM4\_\_ARR automatically and half of the result (TIM4\_\_ARR/2) to TIM4\_\_DR by hardware. It shall be noted that Timer4 must work in Output Mode and the clock division factor of Timer4 shall be configured according to the motor maximum speed. FOC\_\_KFG is computed using

the following algorithm:  $FOC\_KFG = SYSCLK / (2^{TIM4\_CR0[T4PSC]} * f_{base} * x)$ , where, x refers to the expected number of FG signal in one electric cycle. If the result exceeds 65535, the clock division factor TIM4\_CR0[T4PSC] shall be adjusted.

When FOC\_KFG = 0, this feature is disabled, and TIM4\_\_ARR and TIM4\_\_DR keeps unchanged.

## 13.2 FOC Registers

### 13.2.1 FOC\_CR0 (0x409F)

Bit	7	6	5	4	3	2	1	0
Name	OMIF	OMAF	MERRS		RSV	OMAS	ESCMS	EDIS
Type	R	R	R/W	R/W	-	R/W	R/W	R/W
Reset	0	0	0	0	-	0	0	0
Bit	Name	Description						
[7]	OMIF	omega < FOC_EFREQMIN flag. This bit is valid even if FOC_CR1 [EFAE] is 0. 0: omega ≥ FOC_EFREQMIN 1: omega < FOC_EFREQMIN						
[6]	OMAF	omega > FOC_EFREQMIN Flag 0: omega ≤ FOC_EFREQMIN 1: omega > FOC_EFREQMIN						
[5:4]	MERRS	The maximum error of SMO Algorithm Select bit 00: 0.5 01: 0.25 10: 0.125 11: 1.0						
[3]	RSV	Reserved						
[2]	OMAS	Output selection when omega is too large When omega[15:8] > FOC_EFREQMAX, the output OME is set as: 0: FOC_EFREQMAX*256 1: FOC_EFREQHOLD						
[1]	ESCMS	Angle Mode Select bit 0: Internal Test Mode 1: Recommended Mode						
[0]	EDIS	FOC_EALP/FOC_EBET Auto-computation Disabled 0: Not forbid 1: Forbid						

### 13.2.2 FOC\_CR1 (0x40A0)

Bit	7	6	5	4	3	2	1	0
Name	OVMDL	EFAE	RFAE	ANGM	CSM		RSV	SVPWMEN
Type	R/W	R/W	R/W	R/W	R/W	R/W	-	R/W
Reset	0	0	0	0	0	0	-	0
Bit	Name	Description						
[7]	OVMDL	Overmodulation Enable 0: Disable 1: Enable						
[6]	EFAE	Forced Angle of Estimator Enable When this feature is enabled, angle mode is determined by the estimator, and it switches to estimated angle mode automatically. 0: Disable 1: Enable						
[5]	RFAE	Forced Ramping Angle Enable When this feature is enabled, angle mode is determined by the ramping module. After ramping, it switches to estimated mode or forced pulling mode according						

		to FOC_CR1[ANGM]. FOC_CR1[RFAE] is cleared to “0” by hardware as well. 0: Disable 1: Enable
[4]	ANGM	Angle Mode When FOC_CR1[RFAE] = 0, angle mode is determined by this bit. When FOC_CR1[RFAE] = 1, angle mode is determined by this bit after ramping. 0: Forced Pulling Angle Mode 1: Estimated Angle of Estimator Mode
[3:2]	CSM	Current Sampling Mode 00: Single-shunt Current Sampling 01: Dual-shunt Current Sampling 10: Reserved 11: Triple-shunt Current Sampling
[1]	RSV	Reserved
[0]	SVPWMEN	SVPWM Module Enable 0: Disable 1: Enable

### 13.2.3 FOC\_CR2 (0x40A1)

Bit	7	6	5	4	3	2	1	0
Name	ESEL	ICLR	F5SEG	DSS	CSOC		UQD	UDD
Type	R/W	R/W1	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[7]	ESEL	Angle Estimator Mode Select Bit 0: SMO 1: PLL (phase-locked loop). FOC_KSILDE register is FOC_PLLKP of PI controller, and FOC_KLPFMIN register is FOC_PLLKI of PI controller.
[6]	ICLR	Clear FOC_IAMAX/FOC_IBMAX/FOC_ICMAX to “0” 0: No effect 1: The bit is automatically set to “0” after FOC_IAMAX/ FOC_IBMAX/ FOC_ICMAX are cleared to “0”.
[5]	F5SEG	SVPWM Mode Select Bit 0: Continuous SVPWM 1: Discontinuous SVPWM (cannot be selected in single-shunt current sampling mode)
[4]	DSS	Dual/Triple-shunt Current Sampling Mode 0: Sequential Sampling Mode, where current values of two phases are sampled in each carrier period. 1: Alternate Sampling Mode. FOC module completes the calculation in every PWM cycle. The current of one phase is sampled in each PWM cycle, and the current of two phases are sampled alternately in two adjacent PWM cycles.
[3:2]	CSOC	Current Sampling Offset Calibration This bit is written to select the offset of FOC_CSO. In single-shunt current sampling mode, “00” or “11” is written to calibrate itrip offset. In dual-shunt current sampling mode, “01” is written to calibrate ia offset and “10” to calibrate ib offset. In triple-shunt current sampling mode, “01” is written to calibrate ia offset, “10” to calibrate ib offset and “00” or “11” to calibrate ic offset. 00: itrip & ic 01: ia 10: ib 11: itrip & ic
[1]	UQD	q-axis PI controller disabled, where FOC_UQ value is no longer updated by the PI controller. 0: Not forbid 1: Forbid

[0]	UDD	d-axis PI controller disabled, where the FOC_UD value is no longer updated by the PI controller. 0: Not forbid 1: Forbid
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### 13.2.4 FOC\_CR3 (0x409E)

Bit	7	6	5	4	3	2	1	0
Name	EFAM	TAM D	MFP_E N	FOC_THECOMP_ DIS	FOCFE N	HALL_PLL_ EN	TSMIN H9	TSMINH 8
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[7]	EFAM	OMEGA Startup Force Enable When FOC_CR1[EFAE] is set to “0” and FOC_CR1[EFAM] to “1”, FOC_OMEGA register is forced to stay as FOC_EFREQHOLD. 0: Disable 1: Enable
[6]	TAMD	Angle Calculation Method The angle derived from atan (ealpha/ebeta) is used as FOC_THETA. 0: Disable 1: Enable
[5]	MFP_EN	Adaptive Observer Enable 0: Disable 1: Enable
[4]	FOC_THECOMP_ DIS	Algorithm w/o Compensation Angle Enable Bit. With this feature enabled, angle compensation of 26.5° is not executed even if the SMO or AO algorithm is selected. 0: Disable 1: Enable
[3]	FOCFEN	FOC Force Enable Bit When DRV_CR[MESEL] is set to “1”, FOC module performs calculation even if DRV_CR[OCS] = 0. 0: Disable 1: Enable
[2]	HALL_PLL_EN	HALL Filter in PLL Mode Enable Bit In HALL mode, HALL angle written to FOC_THETA bit is sent to other modules after smooth switching. 0: Disable 1: Enable
[1:0]	TSMINH	Scale up by two bits of FOC_TSMIN, forming 10-bit data with the 0x40a2 register

### 13.2.5 FOC\_TSMIN (0x40A2)

Bit	7	6	5	4	3	2	1	0
Name	FOC TSMIN							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[7:0]	FOC_TSMIN	Single-shunt Current Sampling Mode: minimum window for sampling Dual/triple-shunt Current Sampling Mode: deadtime compensation Range [0, 255] TSMIN = sampling window $T_{window}$ + deadtime $T_{DT}$ Example: Assuming that $T_{window} = 1\mu s$ , $T_{DT} = 1\mu s$ , TSMIN = 2 $\mu s$ and carrier period = 62.5 $\mu s$ , then FOC TSMIN = (1 + 1)/62.5*4096 = 131.

**13.2.6 FOC\_TGLI (0x40A3)**

Bit	7	6	5	4	3	2	1	0
Name	FOC TGLI							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	FOC_TGLI	<p>Narrow Pulse Elimination for High-side of the Bridge</p> <p>This feature is designed for high-voltage applications. The high-side of bridge must be longer than a certain time. After this bit is configured, high-side of the bridge is not turned on when the conducting time is less than this value.</p> <p>Range [0, 255]</p> <p>Example: Assuming that it is required to remove narrow pulses with less than 1<math>\mu</math>s width, deadtime <math>T_{DT} = 1\mu</math>s, and carrier period = 62.5<math>\mu</math>s, then <math>FOC\_TGLI = (1 + 1)/62.5 * 4096 = 131</math>.</p>						

**13.2.7 FOC\_TBLO (0x40A4)**

Bit	7	6	5	4	3	2	1	0
Name	FOC TBLO							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	FOC_TBLO	<p>Sampling Masking Time in Triple-shunt Current Sampling Mode</p> <p>If low-side of the bridge is turned on for less than FOC_TBLO, the current of this phase is not sampled and obtained through special process.</p> <p>Range [0, 255]</p> <p>Example: Assuming that the phase current is not sampled if the low-side is turned on for less than 1<math>\mu</math>s, then <math>FOC\_TBLO = 1000ns/41.67ns = 24</math>.</p>						

**13.2.8 FOC\_TRGDLY (0x40A5)**

Bit	7	6	5	4	3	2	1	0
Name	FOC TRGDLY							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	FOC_TRGDLY	<p>Time Configuration for Current Sampling</p> <p>When FOC_TRGDLY is set to "0", FOC module samples the current as follows.</p> <p>Single-shunt Current Sampling Mode: Midpoint between deadtime and applied time of active voltage vector</p> <p>Dual/Triple-shunt Current Sampling Mode: Midpoint of vector 000 (Driver count value = 0). Range [-128, 127]</p> <p>Single-shunt Current Sampling Mode: If FOC_TRGDLY = 5, it delays by <math>5 * T = 208ns</math> to sample the current, and if FOC_TRGDLY = 0xFB (complement) or FOC_TRGDLY = -5, it advances by <math>5 * T = 208ns</math>.</p> <p>Dual-shunt/Triple-shunt Current Sampling Mode: If FOC_TRGDLY = 0x85 (the highest bit, and the remaining 7 bits are absolute values) and Driver timer counts down, it samples the current at <math>5 * T = 208ns</math> before an overflow event occurs. If FOC_TRGDLY = 5 and Driver timer counts up, it samples the current at <math>5 * T = 208ns</math> after an overflow event occurs.</p>						



**13.2.9 FOC\_CS0 (0x40A6, 0x40A7)**

FOC_CS0H(0x40A6)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_CS0[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	1	0	0	0	0	0	0
FOC_CS0L(0x40A7)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_CS0[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_CS0	<p>Current Sampling Offset</p> <p>FOC_CR2[CSOC] is configured to select the current, and FOC_CS0 is written to calibrate current sampling offset of itrip in single-shunt current sampling mode, ia, ib in dual-shunt current sampling mode and ia, ib and ic in triple-shunt current sampling mode.</p> <p>Range [0, 32767]. The MSB is always 0</p> <p>Example: Assuming that the ADC voltage falls within 0V ~ 5V with a reference value of 2.5V, then <math>FOC\_CS0 = 2.5V/5V * 32768 = 16384(0x4000)</math></p>						

**13.2.10 FOC\_RTHERSTEP (0x40A8, 0x40A9)**

FOC_RTHERSTEPH(0x40A8)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_RTHERSTEP[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_RTHERSTEPL(0x40A9)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_RTHERSTEP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_RTHERSTEP	<p>Speed of Ramping Module</p> <p>FOC_RTHERSTEP is an internal 32-bit variable. MSB is sign bit. High-order 16 bits are written by software. Range [-32768.32767]</p> <p><math>FOC\_RTHERSTEP(32\text{ bits}) = FOC\_RTHERSTEP(32\text{ bits}) + FOC\_RTHERACC(16\text{ low-order bits})</math></p> <p><math>THETA\_OL(16\text{ bits}) = THETA\_OL(16\text{ bits}) + FOC\_RTHERSTEP(16\text{ high-order bits})</math></p>						

**13.2.11 FOC\_RTHERACC (0x40AA, 0x40AB)**

FOC_RTHERACCH(0x40AA)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_RTHERACC[15:8]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
FOC_RTHERACCL(0x40AB)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_RTHERACC[7:0]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						

[15:0]	FOC_RTHEACC	Ramping acceleration, FOC_RTHEACC is an internal 32-bit variable. MSB is sign bit. Low-order 16 bits are written by software, and high-order 16 bits are always 0. Range [-32768, 32767] FOC_RTHESTEP (32 bits) = FOC_RTHESTEP (32 bits) + FOC_RTHEACC (16 low-order bits) THETA_OL (16 bits) = THETA_OL (16 bits) + FOC_RTHESTEP (16 high-order bits)
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### 13.2.12 FOC\_EOMELPF (0x40AA, 0x40AB)

FOC_EOMELPFH(0x40AA)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_EOMELPF[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC_EOMELPFL(0x40AB)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_EOMELPF[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_EOMELPF	Filtered Estimated Speed of Estimator The filter coefficient is FOC_EOMEKLPF, and the LPF frequency is the PWM cycle. Range [-32768, 32767]						

### 13.2.13 FOC\_RTHECNT (0x40AC)

Bit	7	6	5	4	3	2	1	0
Name	FOC_RTHECNT							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	FOC_RTHECNT	Max. ramping counts = FOC_RTHECNT*256 When ramping feature is enabled, the ramping angle increases in each PWM cycle. After FOC_RTHECNT*256 times, ramping feature is disabled.						

### 13.2.14 FOC\_THECOR (0x40AD)

Bit	7	6	5	4	3	2	1	0
Name	FOC_THECOR							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R
Reset	0	0	0	0	0	0	0	1
Bit	Name	Description						
[7:0]	FOC_THECOR	Angle smooth switching correction: The step value of angle smooth switching after ramping. The format is the same as FOC_THETA. Range [0, 255]						

### 13.2.15 FOC\_\_EMF (0x40AE, 0x40AF)

FOC_EMFH(0x40AE)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_EMF[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC_EMFL(0x40AF)								
Bit	7	6	5	4	3	2	1	0

Name	FOC_EMF[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC__EMF		Estimated BEMF of Estimator This value is the root of sum of square of FOC__EALP and square of FOC__EBET. Range [0, 32767]					

### 13.2.16 FOC\_THECOMP (0x40AE, 0x40AF)

FOC_THECOMP(0x40AE)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_THECOMP[15:8]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
FOC_THECOMPL(0x40AF)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_THECOMP[7:0]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC_THECOMP		Angle Compensation Value The output angle FOC__THETA is derived from estimated angle of the estimator (FOC__ETHETA) + compensation value; the format is same as that of FOC__THETA. Range [-32768, 32767]					

### 13.2.17 FOC\_DMAX (0x40B0, 0x40B1)

FOC_DMAXH(0x40B0)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_DMAX[15:8]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
FOC_DMAXL(0x40B1)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_DMAX[7:0]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC_DMAX		Max. output of d-axis PI controller. Range [-32768, 32767]					

### 13.2.18 FOC\_\_OMEEST (0x40B0, 0x40B1)

FOC__OMEESTH(0x40B0)								
Bit	15	14	13	12	11	10	9	8
Name	FOC__OMEEST[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC__OMEESTL(0x40B1)								
Bit	7	6	5	4	3	2	1	0
Name	FOC__OMEEST[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					

[15:0]	FOC_OMEEST	FOC Calculated Speed of Estimator. Range (0, 32767)
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**13.2.19 FOC\_DMIN (0x40B2, 0x40B3)**

FOC DMINH(0x40B2)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_DMIN[15:8]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
FOC DMINL(0x40B3)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_DMIN[7:0]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_DMIN	Min. output of d-axis PI controller Range [-32768, 32767]						

**13.2.20 FOC\_ATAN\_THETA(0x40B2, 0x40B3)**

FOC ATAN THETAH(0x40B2)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_ATAN_THETA[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC ATAN THETAL(0x40B3)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_ATAN_THETA[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_ATAN_THETA	Angle in ATAN mode, directly calculated by FOC_EALP/FOC_EBET Range (-32768, 32767)						

**13.2.21 FOC\_QMAX (0x40B4, 0x40B5)**

FOC QMAXH(0x40B4)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_QMAX[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC QMAXL(0x40B5)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_QMAX[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_QMAX	Max. output of q-axis PI controller Range [-32768, 32767]						

**13.2.22 FOC\_QMIN (0x40B6, 0x40B7)**

FOC_QMINH(0x40B6)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_QMIN[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_QMINL(0x40B7)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_QMIN[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_QMIN	Min. output of q-axis PI controller Range [-32768, 32767]						

**13.2.23 FOC\_\_UD (0x40B8, 0x40B9)**

FOC_UDH(0x40B8)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_UD[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_UDL(0x40B9)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_UD[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC__UD	d-axis voltage calculated by d-axis PI controller Range [-32768, 32767]						

**13.2.24 FOC\_\_UQ (0x40BA, 0x40BB)**

FOC_UQH(0x40BA)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_UQ[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_UQL(0x40BB)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_UQ[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC__UQ	q-axis voltage calculated by q-axis PI controller Range [-32768, 32767]						

**13.2.25 FOC\_\_ID (0x40BC, 0x40BD)**

FOC_IDH(0x40BC)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_ID[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC_IDL(0x40BD)								

Bit	7	6	5	4	3	2	1	0
Name	FOC_ID[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC_ID		d-axis current from coordinate transformation. Range [-32768, 32767]					

### 13.2.26 FOC\_IQ (0x40BE, 0x40BF)

FOC_IQH(0x40BE)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_IQ[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC_IQL(0x40BF)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_IQ[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC_IQ		q-axis current from coordinate transformation; Range [-32768, 32767]					

### 13.2.27 FOC\_IBET (0x40C0, 0x40C1)

FOC_IBETH(0x40C0)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_IBET[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC_IBETL(0x40C1)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_IBET[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC_IBET		$\beta$ -axis current from coordinate transformation. Range [-32768, 32767]					

### 13.2.28 FOC\_IQ\_LPFK (0x40C0)

Bit	7	6	5	4	3	2	1	0
Name	FOC_IQ_LPFK							
Type	W	W	W	W	W	W	W	W
Reset	1	1	1	1	1	1	1	1
Bit	Name		Description					
[7:0]	FOC_IQ_LPFK		LPF coefficient of FOC_IQ, set to 0xFF by default Range (0, 255)					

### 13.2.29 FOC\_ID\_LPFK (0x40C1)

Bit	7	6	5	4	3	2	1	0
Name	FOC_IQ_LPFK							
Type	W	W	W	W	W	W	W	W
Reset	1	1	1	1	1	1	1	1

Bit	Name	Description
[7:0]	FOC_ID_LPFK	LPF coefficient of FOC_ID, set to 0xFF by default Range (0, 255)

### 13.2.30 FOC\_\_VBET (0x40C2, 0x40C3)

FOC_VBETH(0x40C2)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_VBET[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC_VBETL(0x40C3)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_VBET[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC__VBET	$\beta$ -axis Output Voltage of FOC Module Range [-32768, 32767]						

### 13.2.31 FOC\_UDCPS (0x40C2, 0x40C3)

FOC_UDCPSH(0x40C2)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_UDCPS[15:8]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
FOC_UDCPSL(0x40C3)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_UDCPS[7:0]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_UDCPS	d-axis Voltage Compensation Value The result of d-axis PI controller (FOC__UD) added to FOC_UDCPS is transferred to the next module. Range [-32768, 32767]						

### 13.2.32 FOC\_UQCPS (0x40C4, 0x40C5)

FOC_UQCPSH(0x40C4)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_UQCPS[15:8]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
FOC_UQCPSL(0x40C5)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_UQCPS[7:0]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_UQCPS	q-axis Voltage Compensation Value The result of q-axis PI controller (FOC__UD) added to FOC_UQCPS is transferred to the next module. Range [-32768, 32767]						

**13.2.33 FOC\_VALP (0x40C4, 0x40C5)**

FOC VALPH(0x40C4)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_VALP[15:8]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
FOC VALPL(0x40C5)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_VALP[7:0]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_VALP	$\alpha$ -axis Output Voltage of FOC Module Range [-32768, 32767]						

**13.2.34 FOC\_FLUX (0x40C6, 0x40C7)**

FOC FLUXH(0x40C6)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_FLUX[15:8]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
FOC FLUXL(0x40C7)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_FLUX[7:0]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_FLUX	Magnetic flux of motor Range (0, 32767)						

**13.2.35 FOC\_IC (0x40C6, 0x40C7)**

FOC ICH(0x40C6)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_IC[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC ICL(0x40C7)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_IC[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_IC	Sampled C Phase Current Range [-32768, 32767]						

**13.2.36 FOC\_LQ (0x40C8, 0x40C9)**

FOC LQH(0x40C8)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_LQ[15:8]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
FOC LQ(0x40C9)								



Bit	7	6	5	4	3	2	1	0
Name	FOC_LQ[7:0]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC_LQ		Q-axis Inductance Range (0, 32767)					

**13.2.37 FOC\_\_IB (0x40C8, 0x40C9)**

FOC_IBH(0x40C8)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_IB[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC_IBL(0x40C9)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_IB[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC__IB		Sampled B Phase Current Range [-32768, 32767]					

**13.2.38 FOC\_LD (0x40CA, 0x40CB)**

FOC_LDH(0x40CA)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_LD[15:8]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
FOC_LD(0x40CB)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_LD[7:0]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC_LD		D-axis Inductance Range (0, 32767)					

**13.2.39 FOC\_\_IA (0x40CA, 0x40CB)**

FOC_IAH(0x40CA)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_IA[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC_IAL(0x40CB)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_IA[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC__IA		Sampled A Phase Current Range [-32768, 32767]					

**13.2.40 FOC\_THETA (0x40CC, 0x40CD)**

FOC THETAH(0x40CC)								
Bit	15	14	13	12	11	10	9	8
Name	FOC THETA[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC THETAL(0x40CD)								
Bit	7	6	5	4	3	2	1	0
Name	FOC THETA[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_THETA	Output Angle of FOC Module Range [-32768, 32767] The bit value -32768 ~ 32767 corresponds to angle range -180°~ 180°. Example: Assuming that FOC_THETA = 8192, the output angle is 8192/32768*180°= 45°.						

**13.2.41 FOC\_ETHETA (0x40CE, 0x40CF)**

FOC ETHETAH(0x40CE)								
Bit	15	14	13	12	11	10	9	8
Name	FOC ETHETA[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC ETHETAL(0x40CF)								
Bit	7	6	5	4	3	2	1	0
Name	FOC ETHETA[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_ETHETA	Read: Output Angle of Estimator (angle before FOC_THECOMP is applied); the format is same as that of FOC_THETA. Write: Start Angle of Estimator Range [-32768, 32767]						

**13.2.42 FOC\_EALP (0x40D0, 0x40D1)**

FOC EALPH(0x40D0)								
Bit	15	14	13	12	11	10	9	8
Name	FOC EALP[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC EALPL(0x40D1)								
Bit	7	6	5	4	3	2	1	0
Name	FOC EALP[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_EALP	$\alpha$ -axis estimated BEMF Range [-32768, 32767]						

**13.2.43 FOC\_\_EBET (0x40D2, 0x40D3)**

FOC EBETH(0x40D2)								
Bit	15	14	13	12	11	10	9	8
Name	FOC EBET[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC EBETL(0x40D3)								
Bit	7	6	5	4	3	2	1	0
Name	FOC EBET[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC__EBET	$\beta$ -axis estimated BEMF Range [-32768, 32767]						

**13.2.44 FOC\_\_EOME (0x40D4, 0x40D5)**

FOC EOMEH(0x40D4)								
Bit	15	14	13	12	11	10	9	8
Name	FOC EOME[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC EOMEL(0x40D5)								
Bit	7	6	5	4	3	2	1	0
Name	FOC EOME[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC__EOME	Output Speed of Estimator Range [-32768, 32767]						

**13.2.45 FOC\_\_UQEX (0x40D6, 0x40D7)**

FOC UQEXH(0x40D6)								
Bit	15	14	13	12	11	10	9	8
Name	FOC UQEX[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC UQEXL(0x40D7)								
Bit	7	6	5	4	3	2	1	0
Name	FOC UQEX[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC__UQEX	Overflow Value of q-axis PI Controller Equation: $FOC\_UQ - FOC\_QMAX$ FOC__UQEX is positive when $FOC\_UQ > FOC\_QMAX$ FOC__UQEX is negative when $FOC\_UQ < FOC\_QMAX$ FOC__UQEX can be used to realize weak magnetic flux control. Range [-32768, 32767]						

**13.2.46 FOC\_KFG (0x40D6, 0x40D7)**

FOC KFGH(0x40D6)								
Bit	15	14	13	12	11	10	9	8
Name	FOC KFG[15:8]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
FOC KFGL(0x40D7)								
Bit	7	6	5	4	3	2	1	0
Name	FOC KFG[7:0]							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_KFG	Coefficient of FG Calculation FOC module performs the calculation based on FOC_EOMELPF and FOC_KFG in each PWM cycle. The result is updated to TIM4__ARR and half of the result (TIM4__ARR/2) to TIM4__DR by hardware. See FG Output Generation for more details. Range [0, 65535]  Note: The clock division factor TIM4_CR0[T4PSC] of Timer4 shall be adjusted if FOC_KFG overflows. When FOC_KFG = 0, this feature is disabled.						

**13.2.47 FOC\_\_POW (0x40D8, 0x40D9)**

FOC POWH(0x40D8)								
Bit	15	14	13	12	11	10	9	8
Name	FOC POW[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC POWL(0x40D9)								
Bit	7	6	5	4	3	2	1	0
Name	FOC POW[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC__POW	Motor Power Range [-32768, 32767]						

**13.2.48 FOC\_EOMEKLPF (0x40D8)**

Bit	7	6	5	4	3	2	1	0
Name	FOC_EOMEKLPF							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	FOC_EOMEKLPF	LPF coefficient of estimated speed FOC_EOMELPF of the estimator LPF is calculated in every PWM cycle. Range [1, 255] mapping [1/32768, 255/32768].						

**13.2.49 FOC\_IAMAX (0x40DA, 0x40DB)**

FOC IAMAXH(0x40DA)								
Bit	15	14	13	12	11	10	9	8
Name	FOC IAMAX[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC IAMAXL(0x40DB)								
Bit	7	6	5	4	3	2	1	0
Name	FOC IAMAX[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_IAMAX	Max. A Phase Current Recorded maximum value of A-phase current; This value may be unreliable unless the motor rotates in a full electrical period. This maximum value will not be cleared to “0” automatically unless FOC_CR2[ICLR] is set to “1”. Range [-32768, 32767]						

**13.2.50 FOC\_IBMAX (0x40DC, 0x40DD)**

FOC IBMAXH(0x40DC)								
Bit	15	14	13	12	11	10	9	8
Name	FOC IBMAX[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC IBMAXL(0x40DD)								
Bit	7	6	5	4	3	2	1	0
Name	FOC IBMAX[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_IBMAX	Max. B Phase Current Recorded maximum value of B-phase current. This value may be unreliable unless the motor rotates in a full electrical period. This value will not be cleared to “0” automatically unless FOC_CR2[ICLR] is set to “1”. Range [-32768, 32767]						

**13.2.51 FOC\_ICMAX (0x40DE, 0x40DF)**

FOC ICMAXH(0x40DE)								
Bit	15	14	13	12	11	10	9	8
Name	FOC ICMAX[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC ICMAXL(0x40DF)								
Bit	7	6	5	4	3	2	1	0
Name	FOC ICMAX[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_ICMAX	Max. C Phase Current Recorded maximum value of C-phase current. This value may be unreliable unless the motor rotates in a full electrical period. This value will not be cleared to “0” automatically unless FOC_CR2[ICLR] is set to “1”. Range [-32768, 32767]						

**13.2.52 FOC\_EFREQMAX (0x406F)**

Bit	7	6	5	4	3	2	1	0
Name	FOC_EFREQMAX[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	1	1	1	1	1	1	1
Bit	Name		Description					
[7:0]	FOC_EFREQMAX		Max. omega When $\omega[15:8] > \text{FOC\_EFREQMAX}$ , the output speed OME is: FOC_CR0[OMAS] = 0: FOC_EFREQMAX*256 FOC_CR0[OMAS] = 1: FOC_EFREQHOLD Range [0, 127] 0 ~ 127 mapping the speed range 0~ 32767.  Note: This bit is invalid when MSB = 1.					

**13.2.53 FOC\_DKP (0x4070, 0x4071)**

FOC DKPH(0x4070)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_DKP[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC DKPL(0x4071)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_DKP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC_DKP		KP of D-axis PI Controller Range (0, 32767); MSB is always 0; Q12 format					

**13.2.54 FOC\_EKP (0x4074, 0x4075)**

FOC EKPH(0x4074)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_EKP[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC EKPL(0x4075)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_EKP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC_EKP		KP of PI controller used for estimated angle of the estimator. MSB is always 0. Q12 format. Range [0, 32767]					

**13.2.55 FOC\_EKI (0x4076, 0x4077)**

FOC EKI(0x4076)								
Bit	15	14	13	12	11	10	9	8
Name	FOC EKI[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC EKI(0x4077)								
Bit	7	6	5	4	3	2	1	0
Name	FOC EKI[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_EKI	KI of PI controller used for estimated angle of the estimator; MSB is always 0; Q15 format. Range [0, 32767]						

**13.2.56 FOC\_KSLIDE (0x4078, 0x4079)**

FOC KSLIDEH(0x4078)								
Bit	15	14	13	12	11	10	9	8
Name	FOC KSLIDE/FOC PLLKP[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC KSLIDEL(0x4079)								
Bit	7	6	5	4	3	2	1	0
Name	FOC KSLIDE/FOC PLLKP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_KSLIDE/FOC_PLLKP	FOC_CR2[ESEL] = 0: SMO gain factor; Q15 format FOC_CR2[ESEL] = 1: KP of PI controller on PLL; Q12 format Range [0, 32767]. MSB is always 0.						

**13.2.57 FOC\_EKLPFMIN (0x407A, 0x407B)**

FOC EKLPFMINH(0x407A)								
Bit	15	14	13	12	11	10	9	8
Name	FOC EKLPFMIN/FOC PLLKPI[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC EKLPFMINH(0x407B)								
Bit	7	6	5	4	3	2	1	0
Name	FOC EKLPFMIN/FOC PLLKPI[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_EKLPFMIN/FOC_PLLKI	FOC_CR2[ESEL] = 0: The minimum value of BEMF low pass filter factor. EKLPF is forced to be this value when it is lower than this value. Q15 format. FOC_CR2[ESEL] = 1: PI controller KI coefficient on PLL. Q15 format. Range [0, 32767], MSB is always 0.						

**13.2.58 FOC\_DKI (0x407C, 0x407D)**

FOC DKIH(0x407C)								
Bit	15	14	13	12	11	10	9	8
Name	FOC DKI[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC DKIL(0x407D)								
Bit	7	6	5	4	3	2	1	0
Name	FOC DKI[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_DKI	KI of D-axis PI Controller Range (0, 32767). MSB is always 0. Q15 format						

**13.2.59 FOC\_OMEKLPF (0x407E, 0x407F)**

FOC OMEKLPFH(0x407E)								
Bit	15	14	13	12	11	10	9	8
Name	FOC OMEKLPF[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC OMEKLPFL(0x407F)								
Bit	7	6	5	4	3	2	1	0
Name	FOC OMEKLPF[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_OMEKLPF	LPF factor of estimated speed of the estimator. MSB is always 0. Q15 format. Range [0, 32767]						

**13.2.60 FOC\_FBASE (0x4080, 0x4081)**

FOC FBASEH(0x4080)								
Bit	15	14	13	12	11	10	9	8
Name	FOC FBASE[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC FBASEL(0x4081)								
Bit	7	6	5	4	3	2	1	0
Name	FOC FBASE[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_FBASE	Frequency Base of Estimator Range [0, 32767] $FOC\_FBASE = fbase * Ts * 32768$ Example: Assuming that $fbase = 200\text{Hz}$ , $Ts = 62.5\mu\text{s}$ , then $FOC\_FBASE = 200 * 0.0000625 * 32768 = 409(0x199)$						



**13.2.61 FOC\_EFREQACC (0x4082, 0x4083)**

FOC_EFREQACCCH(0x4082)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_EFREQACC[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_EFREQACCCL(0x4083)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_EFREQACC[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_EFREQACC	Speed Increment of the Forced Angle Mode. FOC_EFREQACC is an internal 24-bit variable and MSB is sign bit. Low-order 16 bits are written by software. Range [0, 65535] Example: Assuming that fbase = 200Hz and pp (Pole_Pairs) = 4, then speed_base = 60*fbase/pp = 3000rpm. If speed increment = 3rpm, then FOC_EFREQACC = 3rpm/speed_base*32768*256 = 8388(0x20C4).						

**13.2.62 FOC\_EFREQMIN (0x4084, 0x4085)**

FOC_EFREQMINH(0x4084)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_EFREQMIN[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_EFREQMINL(0x4085)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_EFREQMIN[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_EFREQMIN	Switch Threshold of the Estimated Angle FOC_EFREQMIN is an internal 24-bit variable, and MSB is sign bit. High-order 16 bits are written by software. With Forced Angle of Estimator Mode enabled, FOC module outputs forced angle when the estimated angle is smaller than the bit value. Range [-32768, 32767] Example: Assuming that fbase = 200Hz and pp (Pole_Pairs) = 4, then speed_base = 60*fbase/pp = 3000rpm. Assuming that the min. switching speed = 30rpm, then FOC_EFREQMIN = 30rpm/speed_base*32768 = 327(0x147).						

**13.2.63 FOC\_EFREQHOLD (0x4086, 0x4087)**

FOC_EFREQHOLDH(0x4086)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_EFREQHOLD[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_EFREQHOLDL(0x4087)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_EFREQHOLD[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[15:0]	FOC_EFREQHOLD	Maximum Value of Forced Speed of the Estimator FOC_EFREQHOLD is an internal 24-bit variable, and MSB is sign bit. High-order 16 bits are written by the software. Range [-32768, 32767] Example: Assuming that fbase = 200Hz and pp (Pole_Pairs) = 4, then speed_base = 60*fbase/pp = 3000rpm. If max. forced speed = 60rpm, then FOC_EFREQHOLD = 60rpm/speed_base*32768 = 655(0x028F).

### 13.2.64 FOC\_EK3 (0x4088, 0x4089)

FOC_EK3H(0x4088)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_EK3[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_EK3L(0x4089)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_EK3[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_EK3	The 3 <sup>rd</sup> coefficient of the current model in estimator, and MSB is always 0. Q15 format. Range [0, 32767]						

### 13.2.65 FOC\_EK4 (0x408A, 0x408B)

FOC_EK4H(0x408A)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_EK4[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_EK4L(0x408B)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_EK4[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_EK4	The 4 <sup>th</sup> coefficient of the current model in estimator. Q15 format. Range [-32768, 32767]						

### 13.2.66 FOC\_EK1 (0x408C, 0x408D)

FOC_EK1H(0x408C)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_EK1[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_EK1L(0x408D)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_EK1[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_EK1	The 1 <sup>st</sup> coefficient of the current model in estimator, and MSB is always 0. Q15 format. Range [0, 32767]						

**13.2.67 FOC\_EK2 (0x408E, 0x408F)**

FOC_EK2H(0x408E)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_EK2[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_EK2L(0x408F)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_EK2[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_EK2	The 2 <sup>nd</sup> coefficient of the current model in estimator, and MSB is always 0. Q15 format. Range [0, 32767]						

**13.2.68 FOC\_IDREF (0x4090, 0x4091)**

FOC_IDREFH(0x4090)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_IDREF[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_IDREFL(0x4091)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_IDREF[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_IDREF	User-defined d-axis Current Range [-32768, 32767]						

**13.2.69 FOC\_IQREF (0x4092, 0x4093)**

FOC_IQREFH(0x4092)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_IQREF[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_IQREFL(0x4093)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_IQREF[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	FOC_IQREF	User-defined q-axis Current Range [-32768, 32767]						

**13.2.70 FOC\_QKP (0x4094, 0x4095)**

FOC_QKPH(0x4094)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_QKP[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

FOC_QKPL(0x4095)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_QKP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC_QKP		KP coefficient of q-axis PI controller. MSB is always 0. Q12 format. Range [0, 32767] corresponds to range of Q12 [0, 8].					

### 13.2.71 FOC\_QKI (0x4096, 0x4097)

FOC_QKIH(0x4096)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_QKI[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
FOC_QKIL(0x4097)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_QKI[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC_QKI		KI coefficient of q-axis PI controller. MSB is always 0. Q15 format. . The bit value range [0, 32767] corresponds to the Q15 value range [0, 1].					

### 13.2.72 FOC\_\_UDCFLT (0x4098, 0x4099)

FOC_UDCFLTH(0x4098)								
Bit	15	14	13	12	11	10	9	8
Name	FOC__UDCFLT[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
FOC_UDCFLTTL(0x4099)								
Bit	7	6	5	4	3	2	1	0
Name	FOC__UDCFLT[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC__UDCFLT		Filtered Bus Voltage FOC module samples the bus voltage and filters it to obtain FOC__UDCFLT. ADC channel 2 (external voltage divider) can be selected. Range [0, 32767] Example: The bus voltage is scaled down by 1/6 before feeding into the ADC module, ADC VREF = 5V (namely, the sampling range is [0V~30V]) and FOC__UDCFLT = 19661(0x4CCD), then bus voltage = $19661/32768*5V*6 = 18V$ .					

## 14 Timer1

### 14.1 Timer1 Operations

Timer1 consists of a 16-bit up-counting Base Timer and a 16-bit up-counting Reload Timer. Timer1 can be used in the applications of square-wave controlled BLDC motor drive. Timer1 features as follows.

- The 16-bit up-counting Base Timer is used to record the time between twice position detected events or twice phases commutations (60 degree time) and also can be used for forced phase commutation control when phase detection fails.
- The 16-bit up-counting Reload Timer is used to control the time from position detected to phase commutation, as well as masking time for diode freewheeling after phase commutation (prohibit position detection time).
- The 3-bit programmable frequency prescaler divides the system clock. The divided clock is used as the clock source of the two timers.
- Configurable filtering signals and sampling delay for position detection
- Position detection module generates the position signal required for phase commutation according to the input signal
- 7 groups state register control comparator and pre-driver output
- 6 interrupt sources

The internal structure of Timer1 is shown in Figure 14-1.

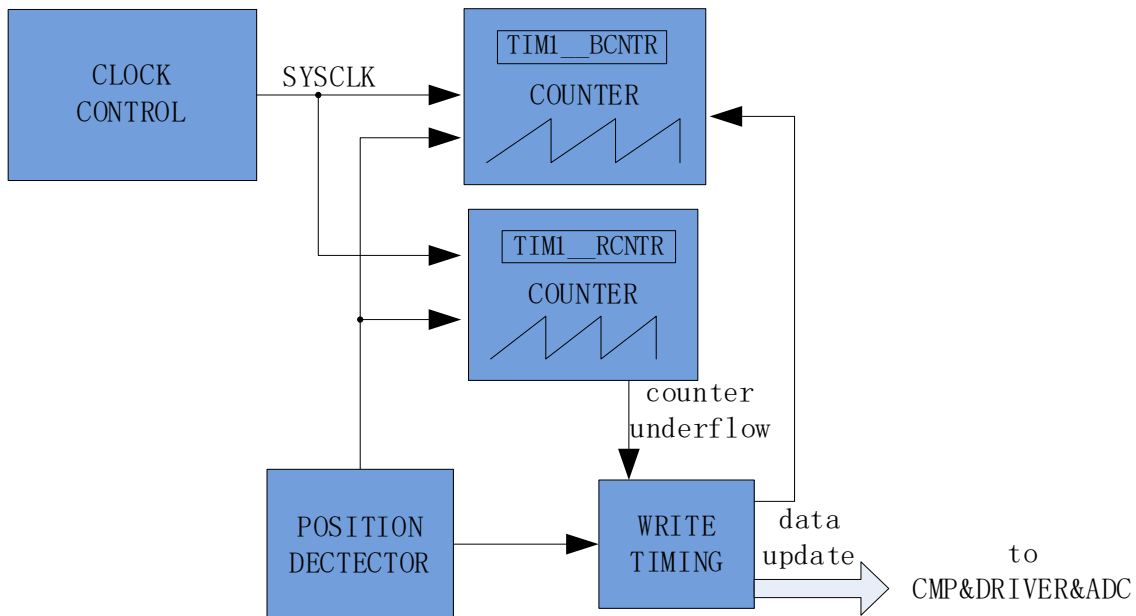


Figure 14-1 Timer1 Internal Structure

### 14.1.1 Timer1 Counter Module

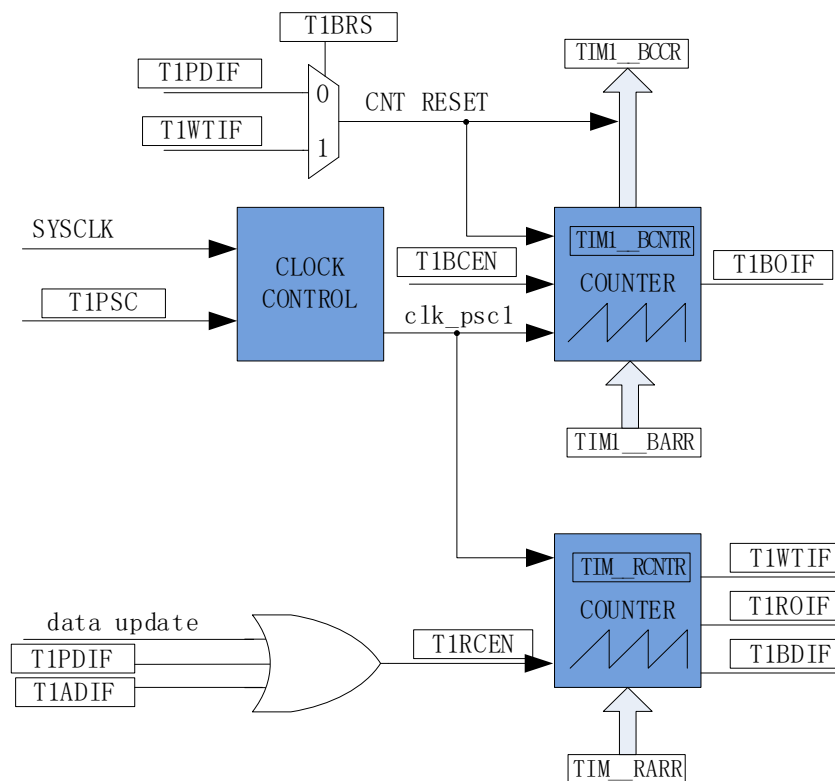


Figure 14-2 Timebase Unit

Timer1 consists of a frequency prescaler, an 16-bit up-counting Base Timer and an 16-bit up-counting Reload Timer.

#### 14.1.1.1 Prescaler

Prescaler divides the system clock frequency and generates the counter clock source for Base Timer and Reload Timer. It offers 8 division coefficients and can be selected through TIM1\_CR3[T1PSC]. Since this register has no buffer, the clock rate is immediately updated after the division coefficient is written. Therefore, the division coefficient shall be configured when both the Basic Timer and Reload Timer are not working. The clock rate  $clk\_psc1 = SYSCLK / (2^{TIM1\_CR3[T1PSC]})$ . The clock rate corresponding to TIM1\_CR3[T1PSC] is shown in Table 14-1.

Table 14-1 Mapping between Clock Rate and TIM1\_CR3[T1PSC] Bit

TIM1_CR3[T1PSC]	Division Factor	clk_psc1(Hz)	TIM1_CR3[T1PSC]	Division Factor	clk_psc1(Hz)
000	1	24M	100	16	1.5M
001	2	12M	101	32	750k
010	4	6M	110	64	375k
011	8	3M	111	128	187.5k

### 14.1.1.2 Base Timer

The Base Timer is a 16-bit up timer with its count value held in the TIM1\_BCNTNTR register. TIM1\_BCNTNTR value is loaded into Capture Register TIM1\_BCCR upon a Position Detected Interrupt TIM1\_SR[T1PDIF] or a Write Timing Interrupt TIM1\_SR[T1WTIF] (selected by TIM1\_CR2[T1BRS] bit). Meanwhile, TIM1\_BCNTNTR bit is cleared to “0” and restarts the counter cycle. TIM1\_BCCR captures the time between two Position Detected Interrupts or two Write Timing Interrupts (i.e. 60° commutation time). These time inputs are averaged multiple times (programmed by the TIM1\_CR0[T1CFLT] bit) before loading the average as a 60° commutation base into the TIM1\_BCOR register. When Auto-load Register TIM1\_BARR is enabled (TIM1\_CR1[BAPE] is set to “1”), TIM1\_BARR loads the value of TIM1\_BCOR by hardware. When count value of TIM1\_BCNTNTR increases to TIM1\_BARR, overflow interrupt flag TIM1\_SR[T1BOIF] of the Basic Timer is set to “1”. If forced commutation feature is enabled, phase commutation occurs and the Basic Timer Register is cleared to “0”. Otherwise, the Basic Timer Register will not be cleared until it counts up to 0xFFFF and becomes overflowed.

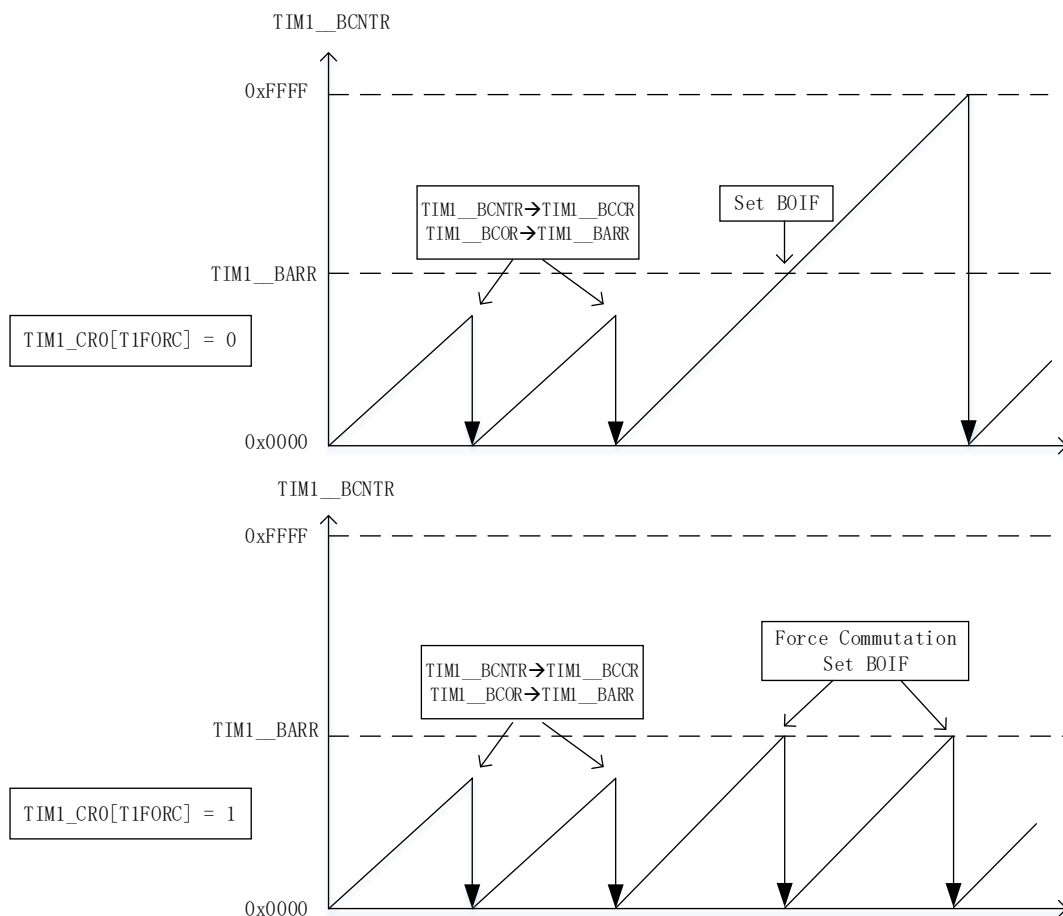


Figure 14-3 Waveform of Base Timer

In Manual mode (TIM1\_IER[T1MAME] = 1), TIM1\_BCNTNTR is cleared by Base Timer Overflow event instead of TIM1\_CR2[T1BRS].

### 14.1.1.3 Reload Timer

The Reload Timer is a 16-bit up timer with its count value held in TIM1\_\_RCNTR. The timer overflows when TIM1\_\_RCNTR increases to TIM1\_\_RARR. It stops counting when TIM1\_SR[T1ROIF] (overflow interrupt flag of the reload counter) is set to “1”, and TIM1\_\_RCNTR and TIM1\_CR0[T1RCEN] are cleared to “0”. TIM1\_CR0[T1RCEN] is set to “1” to restart Reload Timer when position detection interrupt or write timing interrupt is generated.

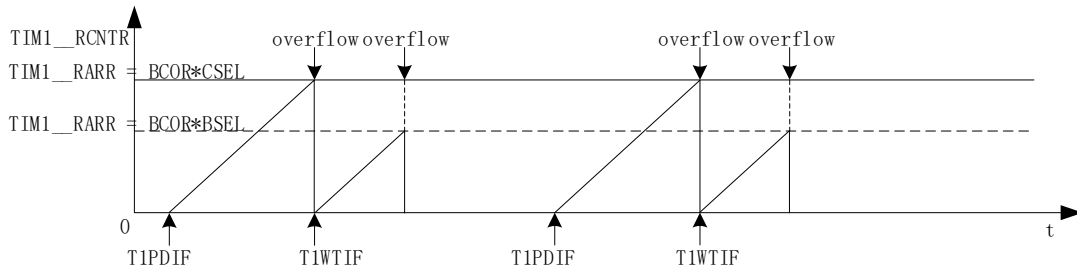


Figure 14-4 Waveform of Reload Timer

### 14.1.2 Position Detection

#### 14.1.2.1 Position Detection Signal

The TIM1\_CR3[T1TIS] bit selects the sources of Position Detection signal, including CMP0/1/2, (CMP Position Detection), GPIO (Hall Sensor Position Detection) or ADC (ACD Position Detection). HALL\_CR[HALLSEL] bit is used to configure GPIO sourced by P1.4/P1.6/P2.1 (Hall signal input after function switching) or P0.2/P3.7/P3.6. TIM1\_CR3[T1INM] bit decides whether CMP/GPIO signal is filtered. A Position Detected Interrupt is generated upon the completion of position detection. Position Detected Interrupts are divided into CMP/GPIO Position Detected Interrupt and ADC Position Detected Interrupt.

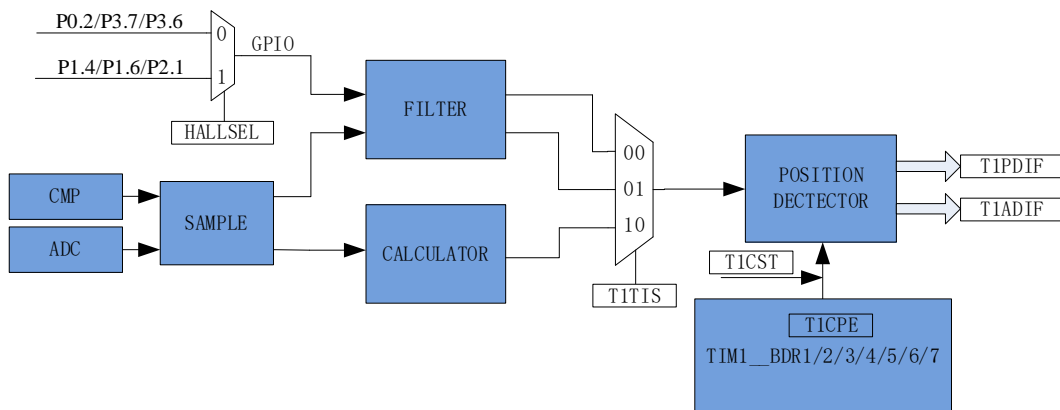


Figure 14-5 Functional Block Diagram of Position Detection

#### 14.1.2.2 CMP/GPIO Position Detection Event

The register bank TIM1\_\_DBR1/2/3/4/5/6/7[T1CPE] is configured to select the active edge of position



detection signal. When an active edge of CMP/GPIO Position Detection signal is detected, it indicates the position detection is successfully done, allowing the CMP/GPIO Position Detected Interrupt Flag TIM1\_SR[T1PDIF] bit to become “1”. TIM1\_CR4[T1CST] bit selects TIM1\_DBR1/2/3/4/5/6/7[T1CPE] timing.

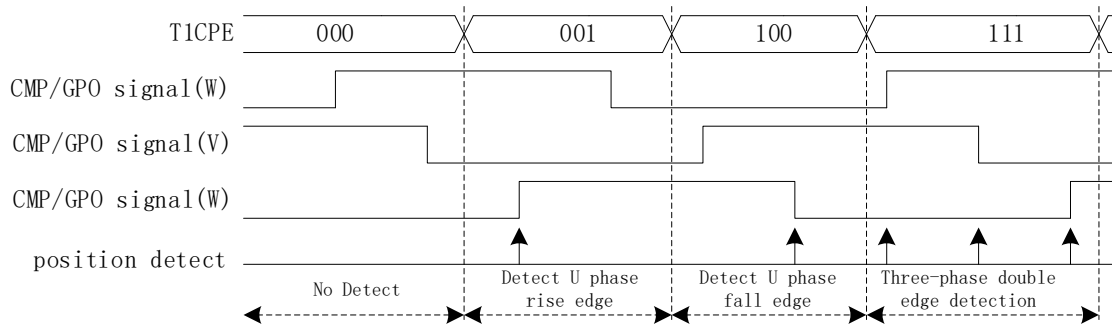


Figure 14-6 Timing Diagram of CMP/GPIO Position Detection

The relation between active edge and TIM1\_DBR1/2/3/4/5/6/7[T1CPE] is shown in Table 14-2.

Table 14-2 Mapping between Active Edge and TIM1\_DBR1/2/3/4/5/6/7[T1CPE]

T1CPE	Description	T1CPE	Description
000	0	100	U-phase corresponding comparator is enabled when falling edge of U-phase is detected.
001	U-phase corresponding comparator is enabled when rising edge of U-phase is detected.	101	W-phase corresponding comparator is enabled when rising edge of W-phase is detected.
010	W-phase corresponding comparator is enabled when falling edge of W-phase is detected.	110	V-phase corresponding comparator is enabled when falling edge of V-phase is detected.
011	V-phase corresponding comparator is enabled when rising edge of V-phase is detected.	111	U+W+V-phase corresponding comparator is enabled when rising or falling edge of U+W+V-phase is detected.

### 14.1.2.3 ADC Position Detection Event

TIM1\_CR3[T1TIS] is configured to select the position detection signal from ADC. Timer1 controls ADC to sample the voltage of active phase and floating phase, which are calculated in the following equation:

$$TIM1\_URES = K \times TIM1\_UCOP - TIM1\_UFLP$$

Where,

K: ADC Position Detection Coefficient

TIM1\_\_UCOP: ADC sampled value of active phase

TIM1\_\_UFLP: ADC sampled value of floating phase

K/TIM1\_\_UCOP/TIM1\_\_UFLP definitions are determined by TIM1\_DBR1/2/3/4/5/6/7[T1CPE]

bit, as detailed in Table 14-3.

Table 14-3 Relation between TIM1\_DBR1/2/3/4/5/6/7[T1CPE] and K, TIM1\_\_UCOP and TIM1\_\_UFLP

T1CPE	Description
000	Reserved
001	TIM1_KR for K, W-phase voltage for TIM1__UCOP, and U-phase voltage for TIM1__UFLP
010	TIM1_KF for K, U-phase voltage for TIM1__UCOP, and W-phase voltage for TIM1__UFLP
011	TIM1_KR for K, U-phase voltage for TIM1__UCOP, and V-phase voltage for TIM1__UFLP
100	TIM1_KF for K, V-phase voltage for TIM1__UCOP, and U-phase voltage for TIM1__UFLP
101	TIM1_KR for K, V-phase voltage for TIM1__UCOP, and W-phase voltage for TIM1__UFLP
110	TIM1_KF for K, W-phase voltage for TIM1__UCOP, and V-phase voltage for TIM1__UFLP
111	Reserved

When TIM1\_\_URES has a negative step or a positive step, an ADC Position Detected Interrupt is generated and TIM1\_SR[T1ADIF] (Position Detected Interrupt Flag) is set to “1”. The position at which ADC Position Detected Interrupt is generated is controlled by setting the coefficient K. In this case, the phase commutation degree can be controlled flexibly.

#### 14.1.2.4 Sampling

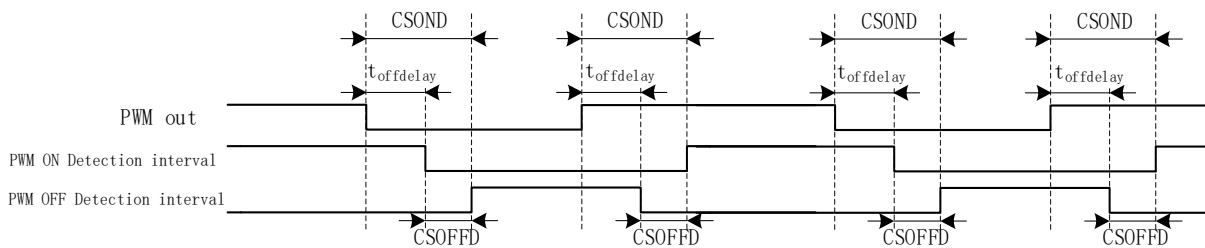


Figure 14-7 Timing Diagram of Sampling

Affected by switching rate of the power device, BEMF signal lags behind PWM output. CMP\_SAMR[CSOFFD], CMP\_SAMR[CSOND] and CMP\_CR4[FAEN] bits shall be set reasonably to adjust the sampling interval and obtain the valid position detection signal. When TIM1\_CR3[T1TIS] = 01 or 10, Timer1 enables CMP0/1/2 to output the compare results between phase BEMF and neutral point, or starts ADC module to sample floating voltage.

See section 29.1.5 for details.

### 14.1.2.5 Filtering

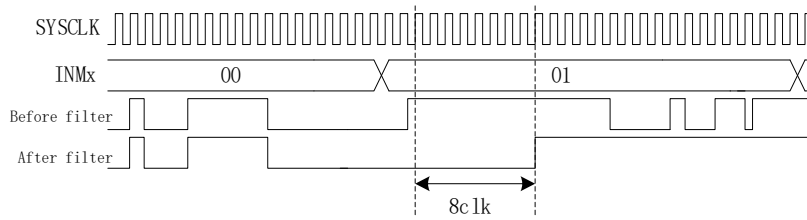


Figure 14-8 Timing Diagram of Filtering Module

According to TIM1\_CR3[T1INM] and CMP\_CR4[FAEN], the filtered pulse width of input noise can be selected as 8/16/24/32/64/96 system clock. After this feature is enabled, the signal is lagged behind about 8/16/24/32/64/96 system clocks.

### 14.1.3 Write Timing Interrupt

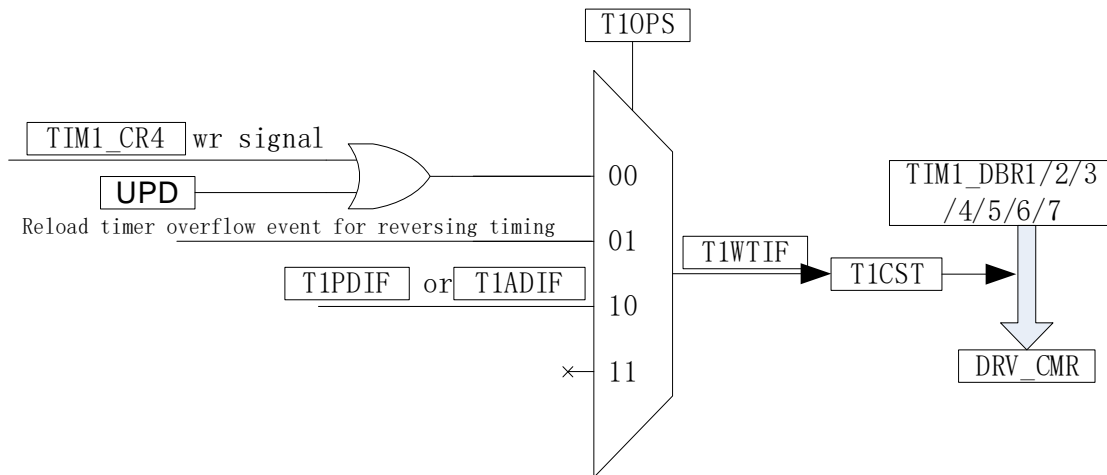


Figure 14-9 Write Timing Block Diagram

When the control logic, predefined in TIM1\_DBR1/2/3/4/5/6/7, is sent to driver register DRV\_CMR, a writing sequence interrupt is generated. The triggered source is selected by the configuration of TIM1\_CR0[T1OPS], and software, Reload Timer overflow event or position detected event can be selected. When a writing sequence interrupt is generated, writing sequence interrupt flag TIM1\_SR[T1WTIF] is set to “1”. If TIM1\_CR4[T1CST] ranges in 001~110, TIM1\_CR4[T1CST] adds 1 automatically.

### 14.1.4 Timer1 Interrupt

Timer1 supports 6 interrupt sources:

- Base Timer overflow interrupt
- Reload Timer overflow interrupt
- Writing sequence interrupt

- Diode Freewheeling End Interrupt
- CMP/GPIO Position Detected Interrupt
- ADC Position Detected Interrupt

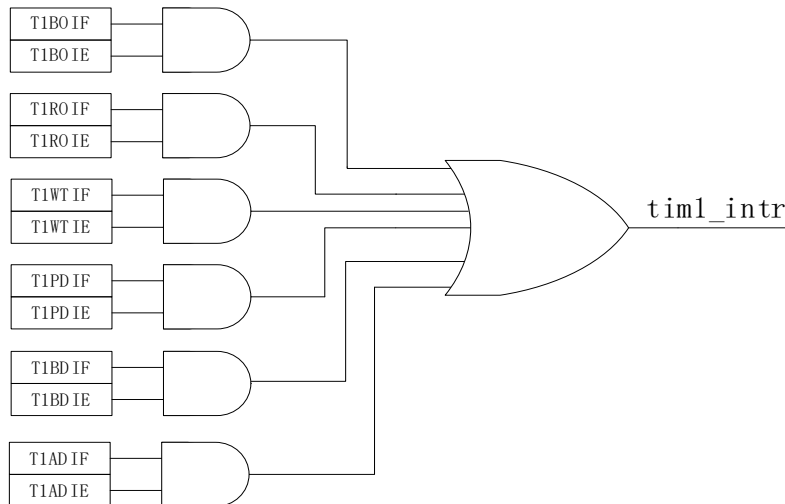


Figure 14-10 Timer1 Interrupt Sources

## 14.2 Square-wave Control Based BLDC Motor

For BLDC motor square-wave control application, Timer1 works with CMP0/1/2 and Driver module to achieve the following features:

- Automatic record of 60 degree time, filtered as 60 degree reference time
- Automatic forced phase commutation when position signal is not detected
- Automatic diode freewheeling masking, i.e., stopping comparator detection during diode freewheeling
- Automatic control of the time from position detected to phase commutation to achieve automatic commutation
- Take over `CMP_CR2[CMP0SEL]` to control CMP0/1/2 automatically
- Comparator signal can be set to avoid ringing at the switch node on power IC, and the signal can be configured to be filtered after sampling
- Take over `DRV_CMCR` register to control six PWM outputs automatically

### 14.2.1 Six-step Phase Commutation of Square Wave Control

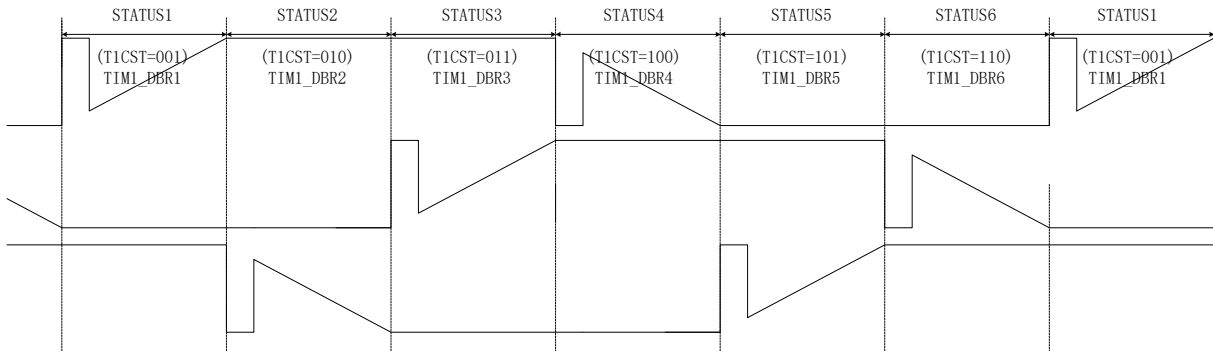


Figure 14-11 Diagram of Six-step Phase Commutation of Square Wave Control

TIM1\_CR4[T1CST] is the commutation state machine. Among them, state 0 is used to output off state, and state 7 is customizable for braking, pre-charging, pre-positioning, startup, etc. States 1~6 are used for six-step automatic commutation, and the state machine TIM1\_CR4[T1CST] automatically adds 1 after phase commutation.

The states 1~7 maps to the TIM1\_DBR1~7. When writing sequence interrupt occurs, TIM1\_DBRx corresponding to the current state is automatically transferred to DRV\_CMRR and CMP\_CR2[COMP0SEL] for phase commutation and position detection.

## 14.2.2 Square Wave Control Working Principle

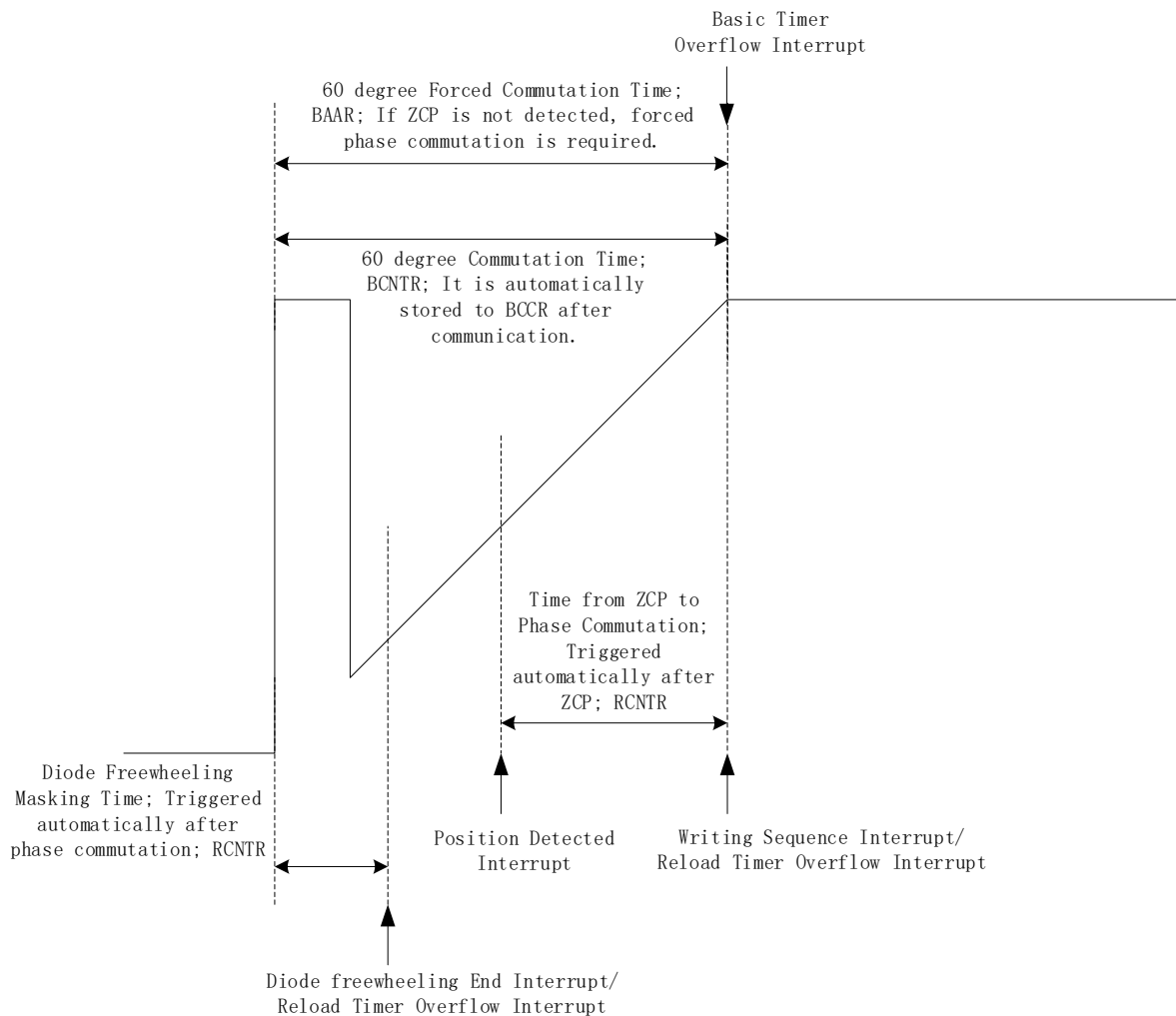


Figure 14-12 Square Wave Control Working Principle

### 14.2.2.1 60° Commutation Base Time

TIM1\_BCCR captures the time of last 60 degree. TIM1\_CR2[T1BRS] is set to “0” to capture the time between two writing sequence interrupts and TIM1\_CR2[T1BRS] to “1” to capture the time between two position detected interrupts.

TIM1\_BCOR is the filtered 60 degree time, i.e., 60 degree base time. TIM1\_CR0[T1CFLT] can select the last 1/2/4/8 TIM1\_BCCR averaged to obtain TIM1\_BCOR.

In square-wave control mode, the diode freewheeling masking time, the time from position detected to commutation, and the time to forced commutation are determined by the 60 degree base time TIM1\_BCOR.

When Base Timer is auto-load enabled (TIM1\_CR1[T1BAPE] = 1), and is reset due to a position detection interrupt or a write timing interrupt, TIM1\_BCOR is transferred to TIM1\_BARR to control the forced phase commutation.

### 14.2.2.2 Forced Commutation at 60°

When the motor rotates smoothly, ZCP is generally detected after 30 degrees of rotation after a phase commutation and a position detection interrupt is generated. If ZCP is not detected in 60 degree after the phase commutation, position detection fails and a forced phase commutation is required.

In this case, TIM1\_CR0[T1FORC] is set to “1” to enable the forced commutation feature. During previous commutation, the timer TIM1\_\_BCNTR is cleared to “0” by timing interrupt and restarts counting, while TIM1\_\_BCCR captures the count value held in TIM1\_\_BCNTR, which is filtered and stored in TIM1\_BCOR as the 60 degree base time. When auto-load feature is enabled (TIM1\_CR1[T1BAPE] = 1), the value held in TIM1\_BCOR is loaded into TIM1\_\_BARR after the Base Timer is cleared. If no ZCP is detected in 60 degree after commutation (TIM1\_\_BCNTR matches TIM1\_\_BARR), TIM1\_SR[T1BOIF] (overflow interrupt flag of the Basic Timer) is set to “1” for forced phase commutation, and the timer TIM1\_\_BCNTR is cleared to “0”. But if a ZCP is detected within 60 degrees after phase commutation, even when  $TIM1\_BCNTR > TIM1\_BARR$ , the forced commutation will not be triggered and TIM1\_SR[T1BOIF] will not be set to “1”. When forced commutation feature is disabled (TIM1\_CR0[T1FORC] = 0) and  $TIM1\_BCNTR > TIM1\_BARR$ , the interrupt flag TIM1\_SR[T1BOIF] is set to “1” and no forced phase commutation is automatically performed. Phase commutation can be performed manually by Basic Timer overflow interrupt flag and the position detected interrupt flag.

### 14.2.2.3 Diode Freewheeling Masking

After the commutation, inductance energy of the phase is released to the power supply or ground through the diode since the original active phase becomes a floating phase. During diode freewheeling, the floating phase BEMF signal cannot be measured. By masking comparator signal or ADC sampling value during diode freewheeling time, wrong commutation caused by wrong signal generated by the freewheeling is avoided. After freewheeling masking, the freewheeling masking end interrupt flag TIM1\_SR[T1BDIF] is generated.

Freewheeling masking time is set by TIM1\_CR1[BSEL] with the formula: Masking angle =  $TIM1\_CR1[BSEL]/128*60^\circ$ .

### 14.2.2.4 Angle of Position Detected to Commutation

After commutation, a ZCP is detected (generating a position detected interrupt) and the hardware starts counting according to the software-set time between ZCP and the commutation. After the counting ends, the hardware automatically implements phase commutation and generates the writing sequence interrupt flag TIM1\_SR[T1WTIF].

The time between ZCP and commutation is set by TIM1\_CR2[CSEL] with the formula: Commutation angle =  $TIM1\_CR2[CSEL]/128*60^\circ$ .

### 14.2.2.5 Cycle-by-cycle Current Limiting

See section 29.1.1.2.

## 14.3 Timer1 Registers

### 14.3.1 TIM1\_CR0 (0x4068)

Bit	7	6	5	4	3	2	1	0
Name	T1RWEN	T1CFLT		T1FORC	T1OPS		T1BCEN	T1RCEN
Type	W1	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	T1RWEN	Write to TIM1_CR0[T1RCEN] Enable 0: No effect 1: When TIM1_CR0 is updated, TIM1_CR0[T1RWEN] and TIM1_CR0[T1RCEN] shall be configured simultaneously to enable or disable TIM1_CR0[T1RCEN]. A write of “0x81” to TIM1_CR0 enables TIM1_CR0[T1RCEN], and “0x80” to disables TIM1_CR0[T1RCEN].						
[6:5]	T1CFLT	60 Degree Base Time Filtering Selection The average of previous x times 60 degree (TIM1__BCCR) is used as the base time (TIM1__BCOR). 00: 1 times 60 degree 01: 2 times 60 degree 10: 4 times 60 degree 11: 8 times 60 degree						
[4]	T1FORC	Forced Phase Commutation at 60° Enable 0: Disable 1: Enable  Note: If a ZCP is detected, forced phase commutation will not be implemented even if this bit is enabled.						
[3:2]	T1OPS	Commutation Trigger Signal Select The bit selects the trigger signal for TIM1_DBRx to transfer data to DRV_CMRR. 00: The transfer is triggered upon a write of “1” to TIM1_IER[T1UPD] in software or on a write to TIM1_CR4[T1CST]. 01: The transfer is triggered upon an overflow interrupt of reload timer commutation counter. 10: The transfer is triggered upon a Position Detected Interrupt. 11: Reserved						
[1]	T1BCEN	Base Timer Enable 0: Disable 1: Enable						
[0]	T1RCEN	Reload Timer Enable When TIM1_CR0 is updated, TIM1_CR0[T1RWEN] and TIM1_CR0[T1RCEN] must be configured simultaneously to enable or disable TIM1_CR0[T1RCEN]. A write of “0x81” to TIM1_CR0 enables TIM1_CR0[T1RCEN] and “0x80” disables TIM1_CR0[T1RCEN]. TIM1_CR0[T1RCEN] is automatically enabled upon a Position Detected Interrupt and a Write Timing Interrupt. TIM1_CR0[T1RCEN] is cleared to “0” by hardware upon a Reload Timer Overflow Interrupt. TIM1_CR0[T1RCEN] cannot be automatically enabled or disabled by hardware in Manual mode. 0: Disable 1: Enable						



**14.3.2 TIM1\_CR1 (0x4069)**

Bit	7	6	5	4	3	2	1	0
Name	T1BAPE	BSEL						
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	T1BAPE	TIM1__BARR Register Auto-load Enable With this bit enabled, TIM1__BCOR is written to TIM1__BARR when Basic Timer is reset due to a Position Detected Interrupt or a Write Timing Interrupt. It is used for forced phase commutation at 60° when no ZCP is detected. Setting the device in Manual mode has no effect on TIM1__BARR Register auto-load feature. 0: Disable 1: Enable						
[6:0]	BSEL	Diode Freewheeling Masking Angle Selection The bit is used to configure the angle of diode freewheeling masking after phase commutation. Position is not detected during diode freewheeling masking. Equation: Diode freewheeling masking angle = $TIM1\_CR1[BSEL]/128 \times 60^\circ$  Note: This bit is invalid in Manual mode.						

**14.3.3 TIM1\_CR2 (0x406A)**

Bit	7	6	5	4	3	2	1	0
Name	T1BRS	CSEL						
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	T1BRS	Base Timer Reset Source Select This bit is invalid in Manual mode ( $TIM1\_IER[T1MAME] = 1$ ). TIM1__BCNTR can only be cleared by a BCNTR Overflow Interrupt. 0: Write Timing Reset 1: Position Detected Interrupt Reset						
[6:0]	CSEL	Phase Commutation Angle Select After a position detected event, phase commutation is implemented after the degree configured by TIM1_CR2[CSEL]. Equation: Commutation angle = $TIM1\_CR2[CSEL]/128 \times 60^\circ$						

**14.3.4 TIM1\_CR3 (0x406B)**

Bit	7	6	5	4	3	2	1	0
Name	RSV	T1PSC			T1TIS		T1INM	
Type	-	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	0	0	0	0	1	0	0
Bit	Name	Description						
[7]	RSV	Reserved						
[6:4]	T1PSC	Timer Clock Source Frequency Select These bits are configured to divide the system clock as the clock source for Base Timer and Reload Timer. The clock source frequency of the two timers: 000: 24MHz      001: 12MHz 010: 6MHz      011: 3MHz 100: 1.5MHz    101: 750kHz 110: 375kHz    111: 187.5kHz						
[3:2]	T1TIS	Position Detection Signal Select Flag 00: GPIO (select P1.4, P1.6, P2.1 or P0.2, P3.7, P3.6 according to						

		HALL_CR[HALLSEL] bit) 01: Output signal of CMP0/1/2 10: Output signal of ADC 11: Reserved
[1:0]	T1INM	Filter Pulse Width for Position Detection Signal Select. When pulse width of the input signal is less than the set value, it is filtered as noise. The filtering time changes according to CMP_CR4[FAEN]. When CMP_CR4[FAEN] = 0: 00: 4 system clock cycles 01: 8 system clock cycles 10: 16 system clock cycles 11: 24 system lock cycles When CMP_CR4[FAEN] = 1: 00: 32 system clock cycles 01: 64 system clock cycles 10: 96 system clock cycles 11: 128 system clock cycles

### 14.3.5 TIM1\_CR4 (0x406C)

Bit	7	6	5	4	3	2	1	0														
Name	RSV					T1CST																
Type	-	-	-	-	-	R/W	R/W	R/W														
Reset	-	-	-	-	-	0	0	0														
Bit	Name	Description																				
[7:3]	RSV	Reserved																				
[2:0]	T1CST	Commutation State Machine The state machine corresponds to different TIM1_DBRx at different states. When TIM1_CR4[T1CST] reads 001~111, Timer1 automatically enables or disables CMP0/1/2 according to the TIM1_DBRx[T1CPE]. When TIM1_CR4[T1CST] reads 001~110, Timer1 automatically adds by “1” each cycle upon a Write Timing Interrupt.  Table 14-4 Mapping between TIM1_CR4[T1CST] and TIM1_DBRx																				
		<table border="1"> <thead> <tr> <th>TIM1_CR4[T1CST]</th> <th>TIM1_DBRx</th> <th>TIM1_CR4[T1CST]</th> <th>TIM1_DBRx</th> </tr> </thead> <tbody> <tr> <td>000</td> <td>0</td> <td>100</td> <td>TIM1_DBR4</td> </tr> <tr> <td>001</td> <td>TIM1_DBR1</td> <td>101</td> <td>TIM1_DBR5</td> </tr> <tr> <td>010</td> <td>TIM1_DBR2</td> <td>110</td> <td>TIM1_DBR6</td> </tr> <tr> <td>011</td> <td>TIM1_DBR3</td> <td>111</td> <td>TIM1_DBR7</td> </tr> </tbody> </table>	TIM1_CR4[T1CST]	TIM1_DBRx	TIM1_CR4[T1CST]	TIM1_DBRx	000	0	100	TIM1_DBR4	001	TIM1_DBR1	101	TIM1_DBR5	010	TIM1_DBR2	110	TIM1_DBR6	011	TIM1_DBR3	111	TIM1_DBR7
TIM1_CR4[T1CST]	TIM1_DBRx	TIM1_CR4[T1CST]	TIM1_DBRx																			
000	0	100	TIM1_DBR4																			
001	TIM1_DBR1	101	TIM1_DBR5																			
010	TIM1_DBR2	110	TIM1_DBR6																			
011	TIM1_DBR3	111	TIM1_DBR7																			

### 14.3.6 TIM1\_IER (0x406D)

Bit	7	6	5	4	3	2	1	0
Name	T1UPD	T1MAME	T1ADIE	T1BOIE	T1ROIE	T1WTIE	T1PDIE	T1BDIE
Type	W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	T1UPD	When TIM1_CR0[T1OPS] = 00, a write of “1” to this bit enables data transfer. This bit is cleared to “0” by hardware after “1” is written.						
[6]	T1MAME	Manual Mode Enable With this bit enabled, Basic Timer and Reload Timer acts as separate counters. Details: TIM1_BCNTNTR of the Basic Timer is cleared by a Base Timer Overflow Interrupt, instead of TIM1_CR2[T1BRS] TIM1_CR0[T1RCEN] of the Reload Timer cannot be cleared to “0” or set to “1” automatically, and is operated by software only. TIM1_RCNTNTR of the Reload Timer can be cleared to “0” upon a Reload Timer						

		Overflow Interrupt only. TIM1__RARR of the Reload Timer cannot be updated automatically, and is operated by software only. 0: Disable 1: Enable
[5]	T1ADIE	ADC Position Detected Interrupt Enable 0: Disable 1: Enable
[4]	T1BOIE	Base Timer Overflow Interrupt Enable 0: Disable 1: Enable
[3]	T1ROIE	Reload Timer Overflow Interrupt Enable 0: Disable 1: Enable
[2]	T1WTIE	Write Timing Interrupt Enable 0: Disable 1: Enable
[1]	T1PDIE	CMP/GPIO Position Detected Interrupt Enable 0: Disable 1: Enable
[0]	T1BDIE	Diode Freewheeling Masking Interrupt Enable 0: Disable 1: Enable

### 14.3.7 TIM1\_SR (0x406E)

Bit	7	6	5	4	3	2	1	0
Name	RSV		T1ADIF	T1BOIF	T1ROIF	T1WTIF	T1PDIF	T1BDIF
Type	-	-	R/W0	R/W0	R/W0	R/W	R/W0	R/W0
Reset	-	-	0	0	0	0	0	0
Bit	Name	Description						
[7:6]	RSV	Reserved						
[5]	T1ADIF	ADC Position Detected Interrupt Flag A Position Detected Interrupt is generated when TIM1_DBRx[T1CPE] matches ACD Position Detection signal. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: No effect						
[4]	T1BOIF	Base Timer Overflow Interrupt Flag An overflow event occurs when Basic Timer counts up and TIM1_BCNTN matches with TIM1_BARR. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: No effect						
[3]	T1ROIF	Reload Timer Overflow Interrupt Flag An overflow event occurs and TIM1_RCNTN is cleared to “0” when TIM1_RCNTN matches TIM1_RARR. Read: 0: No Interrupt Pending						

		<p>1: Interrupt Pending</p> <p>Write:</p> <p>0: This bit is cleared to “0”.</p> <p>1: No effect</p>
[2]	T1WTIF	<p>Writing Sequence Interrupt Flag</p> <p>Writing Sequence Interrupt is generated when TIM1_DBRx is transferred to DRV_CMR.</p> <p>Read:</p> <p>0: No Interrupt Pending</p> <p>1: Interrupt Pending</p> <p>Write:</p> <p>0: This bit is cleared to “0”.</p> <p>1: No effect.</p>
[1]	T1PDIF	<p>CMP/GPIO Position Detected Interrupt Flag</p> <p>A position detected interrupt is generated when CMP/GPIO Position Detection matches TIM1_DBRx[T1CPE].</p> <p>Read:</p> <p>0: No Interrupt Pending</p> <p>1: Interrupt Pending</p> <p>Write:</p> <p>0: This bit is cleared to “0”.</p> <p>1: No effect</p>
[0]	T1BDIF	<p>Diode Freewheeling Masking End Interrupt Flag</p> <p>Diode freewheeling masking starts after phase commutation and an interrupt is generated at end.</p> <p>Read:</p> <p>0: No Interrupt Pending</p> <p>1: Interrupt Pending</p> <p>Write:</p> <p>0: This bit is cleared to “0”.</p> <p>1: No effect</p>

### 14.3.8 TIM1\_BCOR (0x4070, 0x4071)

TIM1 BCORH(0x4070)								
Bit	15	14	13	12	11	10	9	8
Name	TIM1 BCOR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIM1 BCORL(0x4071)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1 BCOR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	TIM1__BCOR		The bit is configured to capture filtered count values held in the Base Timer. TIM1__BCCR holds the filtered count value, i.e., 60 Degree Base Time.					

**14.3.9 TIM1\_CR5 (0x4072)**

Bit	7	6	5	4	3	2	1	0
Name	T1POP	T1WTS	RSV		ITRIP DIS	UCOP DIS	T1AFL	
Type	R	R	-	-	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	T1POP	Data Transfer Triggered by Driver Counter Overflow This bit is valid only when TIM_CR0[T1OPS] = 00. With it enabled, data transfer is triggered by Driver Counter Overflow, namely, commuting the phase once every PWM cycle 0: Disable 1: Enable						
[6]	T1WTS	Commutation enabled at PWM OFF to remove narrow pulses. PWM Synchronization Enable 0: Disable 1: Enable						
[5:4]	RSV	Reserved						
[3]	ITRIP_DIS	Bus Current Sampling Disable 0: Enable 1: Disable						
[2]	UCOP_DIS	Active Phase Voltage Sampling Disable 0: Enable 1: Disable						
[1:0]	T1AFL[1:0]	ADC Sampled Voltage Calculation Filtering Counts 00: 1 01: 2 10: 4 11: 8						

**14.3.10 TIM1\_DBR1 (0x4074, 0x4075)**

TIM1_DBR1H(0x4074)								
Bit	15	14	13	12	11	10	9	8
Name	RSV	T1CPE			T1WHP	T1WLP	T1VHP	T1VLP
Type	-	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	0	0	0	0	0	0	0
TIM1_DBR1L(0x4075)								
Bit	7	6	5	4	3	2	1	0
Name	T1UHP	T1UHP	T1WHE	T1WLE	T1VHE	T1VLE	T1UHE	T1ULE
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15]	RSV	Reserved						
[14:12]	T1CPE	Position Detection Input Edge Polarity and Comparator Enable Select This bit is used to define the edge of Position Detection Input and enable or disable the associated comparators. The detected edge in input signal, corresponding to the configuration, generates a position detected interrupt. See CMP/GPIO Position Detection Event and Table 14-2.						
[11]	T1WHP	High-side Output Polarity of W-phase 0: Active High 1: Active Low						
[10]	T1WLP	Low-side Output Polarity of W-phase 0: Active High 1: Active Low						

[9]	T1VHP	High-side Output Polarity of V-phase 0: Active High 1: Active Low
[8]	T1VLP	Low-side Output Polarity of V-phase 0: Active High 1: Active Low
[7]	T1UHP	High-side Output Polarity of U-phase 0: Active High 1: Active Low
[6]	T1ULP	Low-side Output Polarity of U-phase 0: Active High 1: Active Low
[5]	T1WHE	High-side Output Enable of W-phase 0: Disable 1: Enable
[4]	T1WLE	Low-side Output Enable of W-phase 0: Disable 1: Enable
[3]	T1VHE	High-side Output Enable of V-phase 0: Disable 1: Enable
[2]	T1VLE	Low-side Output Enable of V-phase 0: Disable 1: Enable
[1]	T1UHE	High-side Output Enable of U-phase 0: Disable 1: Enable
[0]	T1ULE	Low-side Output Enable of U-phase 0: Disable 1: Enable

Note: The high-side and low-side outputs of W, V and U-phases are complementary and deadtime is automatically added (same for TIM1\_DBR2~TIM1\_DBR7) when TIM1\_DBR1[T1WLE] and TIM1\_DBR1[T1WHE], TIM1\_DBR1[T1VLE] and TIM1\_DBR1[T1VHE] or TIM1\_DBR1[T1ULE] and TIM1\_DBR1[T1UHE] are set to “1”.

### 14.3.11 TIM1\_DBR2 (0x4076, 0x4077)

TIM1_DBR2H(0x4076)								
Bit	15	14	13	12	11	10	9	8
Name	RSV	T1CPE			T1WHP	T1WLP	T1VHP	T1VLP
Type	-	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	0	0	0	0	0	0	0
TIM1_DBR2L(0x4077)								
Bit	7	6	5	4	3	2	1	0
Name	T1UHP	T1ULP	T1WHE	T1WLE	T1VHE	T1VLE	T1UHE	T1ULE
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15]	RSV	Reserved						
[14:12]	T1CPE	Position Detection Input Edge Polarity and Comparator Enable Select This bit is used to define the edge of Position Detection Input and enable or disable the associated comparators. The detected edge in input signal, corresponding to the configuration, generates a position detected interrupt. See CMP/GPIO Position Detection Event and Table 14-2.						

[11]	T1WHP	High-side Output Polarity of W-phase 0: Active High 1: Active Low
[10]	T1WLP	Low-side Output Polarity of W-phase 0: Active High 1: Active Low
[9]	T1VHP	High-side Output Polarity of V-phase 0: Active High 1: Active Low
[8]	T1VLP	Low-side Output Polarity of V-phase 0: Active High 1: Active Low
[7]	T1UHP	High-side Output Polarity of U-phase 0: Active High 1: Active Low
[6]	T1ULP	Low-side Output Polarity of U-phase 0: Active High 1: Active Low
[5]	T1WHE	High-side Output Enable of W-phase 0: Disable 1: Enable
[4]	T1WLE	Low-side Output Enable of W-phase 0: Disable 1: Enable
[3]	T1VHE	High-side Output Enable of V-phase 0: Disable 1: Enable
[2]	T1VLE	Low-side Output Enable of V-phase 0: Disable 1: Enable
[1]	T1UHE	High-side Output Enable of U-phase 0: Disable 1: Enable
[0]	T1ULE	Low-side Output Enable of U-phase 0: Disable 1: Enable

### 14.3.12 TIM1\_DBR3 (0x4078, 0x4079)

TIM1_DBR3H(0x4078)								
Bit	15	14	13	12	11	10	9	8
Name	RSV	T1CPE			T1WHP	T1WLP	T1VHP	T1VLP
Type	-	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	0	0	0	0	0	0	0
TIM1_DBR3L(0x4079)								
Bit	7	6	5	4	3	2	1	0
Name	T1UHP	T1ULP	T1WHE	T1WLE	T1VHE	T1VLE	T1UHE	T1ULE
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15]	RSV	Reserved						
[14:12]	T1CPE	Position Detection Input Edge Polarity and Comparator Enable Select This bit is used to define the edge of Position Detection Input and enable or disable the associated comparators. The detected edge in input signal, corresponding to the configuration, generates a position detected interrupt. See CMP/GPIO Position Detection Event and Table 14-2.						

[11]	T1WHP	High-side Output Polarity of W-phase 0: Active High 1: Active Low
[10]	T1WLP	Low-side Output Polarity of W-phase 0: Active High 1: Active Low
[9]	T1VHP	High-side Output Polarity of V-phase 0: Active High 1: Active Low
[8]	T1VLP	Low-side Output Polarity of V-phase 0: Active High 1: Active Low
[7]	T1UHP	High-side Output Polarity of U-phase 0: Active High 1: Active Low
[6]	T1ULP	Low-side Output Polarity of U-phase 0: Active High 1: Active Low
[5]	T1WHE	High-side Output Enable of W-phase 0: Disable 1: Enable
[4]	T1WLE	Low-side Output Enable of W-phase 0: Disable 1: Enable
[3]	T1VHE	High-side Output Enable of V-phase 0: Disable 1: Enable
[2]	T1VLE	Low-side Output Enable of V-phase 0: Disable 1: Enable
[1]	T1UHE	High-side Output Enable of U-phase 0: Disable 1: Enable
[0]	T1ULE	Low-side Output Enable of U-phase 0: Disable 1: Enable

### 14.3.13 TIM1\_DBR4 (0x407A, 0x407B)

TIM1_DBR4H(0x407A)								
Bit	15	14	13	12	11	10	9	8
Name	RSV	T1CPE			T1WHP	T1WLP	T1VHP	T1VLP
Type	-	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	0	0	0	0	0	0	0
TIM1_DBR4L(0x407B)								
Bit	7	6	5	4	3	2	1	0
Name	T1UHP	T1ULP	T1WHE	T1WLE	T1VHE	T1VLE	T1UHE	T1ULE
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15]	RSV	Reserved						
[14:12]	T1CPE	Position Detection Input Edge Polarity and Comparator Enable Select This bit is used to define the edge of Position Detection Input and enable or disable the associated comparators. The detected edge in input signal, corresponding to the configuration, generates a position detected interrupt. See CMP/GPIO Position Detection Event and Table 14-2.						



[11]	T1WHP	High-side Output Polarity of W-phase 0: Active High 1: Active Low
[10]	T1WLP	Low-side Output Polarity of W-phase 0: Active High 1: Active Low
[9]	T1VHP	High-side Output Polarity of V-phase 0: Active High 1: Active Low
[8]	T1VLP	Low-side Output Polarity of V-phase 0: Active High 1: Active Low
[7]	T1UHP	High-side Output Polarity of U-phase 0: Active High 1: Active Low
[6]	T1ULP	Low-side Output Polarity of U-phase 0: Active High 1: Active Low
[5]	T1WHE	High-side Output Enable of W-phase 0: Disable 1: Enable
[4]	T1WLE	Low-side Output Enable of W-phase 0: Disable 1: Enable
[3]	T1VHE	High-side Output Enable of V-phase 0: Disable 1: Enable
[2]	T1VLE	Low-side Output Enable of V-phase 0: Disable 1: Enable
[1]	T1UHE	High-side Output Enable of U-phase 0: Disable 1: Enable
[0]	T1ULE	Low-side Output Enable of U-phase 0: Disable 1: Enable

#### 14.3.14 TIM1\_DBR5 (0x407C, 0x407D)

TIM1_DBR5H(0x407C)								
Bit	15	14	13	12	11	10	9	8
Name	RSV	T1CPE			T1WHP	T1WLP	T1VHP	T1VLP
Type	-	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	0	0	0	0	0	0	0
TIM1_DBR5L(0x407D)								
Bit	7	6	5	4	3	2	1	0
Name	T1UHP	T1ULP	T1WHE	T1WLE	T1VHE	T1VLE	T1UHE	T1ULE
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15]	RSV	Reserved						
[14:12]	T1CPE	Position Detection Input Edge Polarity and Comparator Enable Select This bit is used to define the edge of Position Detection Input and enable or disable the associated comparators. The detected edge in input signal, corresponding to the configuration, generates a position detected interrupt. See CMP/GPIO Position Detection Event and Table 14-2.						

[11]	T1WHP	High-side Output Polarity of W-phase 0: Active High 1: Active Low
[10]	T1WLP	Low-side Output Polarity of W-phase 0: Active High 1: Active Low
[9]	T1VHP	High-side Output Polarity of V-phase 0: Active High 1: Active Low
[8]	T1VLP	Low-side Output Polarity of V-phase 0: Active High 1: Active Low
[7]	T1UHP	High-side Output Polarity of U-phase 0: Active High 1: Active Low
[6]	T1ULP	Low-side Output Polarity of U-phase 0: Active High 1: Active Low
[5]	T1WHE	High-side Output Enable of W-phase 0: Disable 1: Enable
[4]	T1WLE	Low-side Output Enable of W-phase 0: Disable 1: Enable
[3]	T1VHE	High-side Output Enable of V-phase 0: Disable 1: Enable
[2]	T1VLE	Low-side Output Enable of V-phase 0: Disable 1: Enable
[1]	T1UHE	High-side Output Enable of U-phase 0: Disable 1: Enable
[0]	T1ULE	Low-side Output Enable of U-phase 0: Disable 1: Enable

#### 14.3.15 TIM1\_DBR6 (0x407E, 0x407F)

TIM1_DBR6H(0x407E)								
Bit	15	14	13	12	11	10	9	8
Name	RSV	T1CPE			T1WHP	T1WLP	T1VHP	T1VLP
Type	-	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	0	0	0	0	0	0	0
TIM1_DBR6L(0x407F)								
Bit	7	6	5	4	3	2	1	0
Name	T1UHP	T1ULP	T1WHE	T1WLE	T1VHE	T1VLE	T1UHE	T1ULE
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15]	RSV	Reserved						
[14:12]	T1CPE	Position Detection Input Edge Polarity and Comparator Enable Select This bit is used to define the edge of Position Detection Input and enable or disable the associated comparators. The detected edge in input signal, corresponding to the configuration, generates a position detected interrupt. See CMP/GPIO Position Detection Event and Table 14-2.						

[11]	T1WHP	High-side Output Polarity of W-phase 0: Active High 1: Active Low
[10]	T1WLP	Low-side Output Polarity of W-phase 0: Active High 1: Active Low
[9]	T1VHP	High-side Output Polarity of V-phase 0: Active High 1: Active Low
[8]	T1VLP	Low-side Output Polarity of V-phase 0: Active High 1: Active Low
[7]	T1UHP	High-side Output Polarity of U-phase 0: Active High 1: Active Low
[6]	T1ULP	Low-side Output Polarity of U-phase 0: Active High 1: Active Low
[5]	T1WHE	High-side Output Enable of W-phase 0: Disable 1: Enable
[4]	T1WLE	Low-side Output Enable of W-phase 0: Disable 1: Enable
[3]	T1VHE	High-side Output Enable of V-phase 0: Disable 1: Enable
[2]	T1VLE	Low-side Output Enable of V-phase 0: Disable 1: Enable
[1]	T1UHE	High-side Output Enable of U-phase 0: Disable 1: Enable
[0]	T1ULE	Low-side Output Enable of U-phase 0: Disable 1: Enable

#### 14.3.16 TIM1\_DBR7 (0x4080, 0x4081)

TIM1_DBR7H(0x4080)								
Bit	15	14	13	12	11	10	9	8
Name	RSV	T1CPE			T1WHP	T1WLP	T1VHP	T1VLP
Type	-	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	0	0	0	0	0	0	0
TIM1_DBR7L(0x4081)								
Bit	7	6	5	4	3	2	1	0
Name	T1UHP	T1ULP	T1WHE	T1WLE	T1VHE	T1VLE	T1UHE	T1ULE
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15]	RSV	Reserved						
[14:12]	T1CPE	Position Detection Input Edge Polarity and Comparator Enable Select This bit is used to define the edge of Position Detection Input and enable or disable the associated comparators. The detected edge in input signal, corresponding to the configuration, generates a position detected interrupt. See CMP/GPIO Position Detection Event and Table 14-2.						

[11]	T1WHP	High-side Output Polarity of W-phase 0: Active High 1: Active Low
[10]	T1WLP	Low-side Output Polarity of W-phase 0: Active High 1: Active Low
[9]	T1VHP	High-side Output Polarity of V-phase 0: Active High 1: Active Low
[8]	T1VLP	Low-side Output Polarity of V-phase 0: Active High 1: Active Low
[7]	T1UHP	High-side Output Polarity of U-phase 0: Active High 1: Active Low
[6]	T1ULP	Low-side Output Polarity of U-phase 0: Active High 1: Active Low
[5]	T1WHE	High-side Output Enable of W-phase 0: Disable 1: Enable
[4]	T1WLE	Low-side Output Enable of W-phase 0: Disable 1: Enable
[3]	T1VHE	High-side Output Enable of V-phase 0: Disable 1: Enable
[2]	T1VLE	Low-side Output Enable of V-phase 0: Disable 1: Enable
[1]	T1UHE	High-side Output Enable of U-phase 0: Disable 1: Enable
[0]	T1ULE	Low-side Output Enable of U-phase 0: Disable 1: Enable

#### 14.3.17 TIM1\_\_BCNTR (0x4082, 0x4083)

TIM1 BCNTRH(0x4082)								
Bit	15	14	13	12	11	10	9	8
Name	TIM1 BCNTR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	1	0	0	0	0	0	0	0
TIM1 BCNTRL(0x4083)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1 BCNTR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM1__BCNTR	This bit holds count values of the Base Timer and is used for clocking commutation at 60°. Auto mode: TIM1__BCNTR register selects the reset source according to TIM1_CR2[T1BRS], and TIM1__BCNTR does not restart when TIM1__BCNTR overflow interrupt is generated. Manual mode: TIM1__BCNTR restarts when TIM1__BCNTR overflow interrupt is generated.						

**14.3.18 TIM1\_BCCR (0x4084, 0x4085)**

TIM1_BCCRH(0x4084)								
Bit	15	14	13	12	11	10	9	8
Name	TIM1_BCCR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIM1_BCCRL(0x4085)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_BCCR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM1_BCCR	The bit is configured to capture count values held in Base Timer. Auto mode: When the Base Timer is reset on a Position Detected Interrupt or a Write Timing Interrupt, the count values before the reset are stored into TIM1_BCCR. Manual mode: When the Base Timer is reset on an Overflow Interrupt, the count values before the reset are stored into TIM1_BCCR.						

**14.3.19 TIM1\_BARR (0x4086, 0x4087)**

TIM1_BARRH(0x4086)								
Bit	15	14	13	12	11	10	9	8
Name	TIM1_BARR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIM1_BARRL(0x4087)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_BARR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM1_BARR	When the count value of the Base Timer equals to TIM1_BARR value, an overflow interrupt is generated and the counter is cleared to "0".						

**14.3.20 TIM1\_RARR (0x4088, 0x4089)**

TIM1_RARRH(0x4088)								
Bit	15	14	13	12	11	10	9	8
Name	TIM1_RARR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIM1_RARRL(0x4089)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_RARR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM1_RARR	Auto-Reload Value in Reload Timer When count of the Reload Timer is equal to TIM1_RARR, an overflow interrupt is generated and the value of the timer is cleared to "0". Auto mode: The value of diode freewheeling masking angle held in						

		TIM1_CR1[BSEL] is updated to TIM1_RARR when a Write Sequence Interrupt is generated. The value of commutation angle held in TIM1_CR2[CSEL] is updated to TIM1_RARR when a Position Detected Interrupt occurs. Manual mode: TIM1_RARR is not updated automatically.
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### 14.3.21 TIM1\_RCNTR (0x408A, 0x408B)

TIM1_RCNTRH(0x408A)								
Bit	15	14	13	12	11	10	9	8
Name	TIM1_RCNTR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	1	1	1	1	1	1	1	1
TIM1_RCNTRL(0x408B)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_RCNTR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	1	1	1	1	1	1	1	1
Bit	Name	Description						
[15:0]	TIM1_RCNTR	Count value of the Reload Timer for counting numbers of diode freewheeling masking and ZCP to phase commutation. Note: In Manual mode, TIM1_RCNTR is cleared to “0” only by a Reload Timer overflow interrupt.						

### 14.3.22 TIM1\_UCOP (0x408C, 0x408D)

TIM1_UCOPH(0x408C)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_UCOP[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIM1_UCOPL(0x408D)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_UCOP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM1_UCOP	ADC Sampled Value of active phase voltage (second-highest bit alignment)						

### 14.3.23 TIM1\_UFLP (0x408E, 0x408F)

TIM1_UFLPH(0x408E)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_UCOP[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIM1_UFLPL(0x408F)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_UCOP[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM1_UFLP	ADC Sampled Value of floating phase voltage (second-highest bit alignment)						

**14.3.24 TIM1\_URES (0x4090, 0x4091)**

TIM1_URESH(0x4090)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_URES[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIM1_URES[7:0]								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_URES[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM1_URES	Result of ADC Position Detection formula; Q15 format						

**14.3.25 TIM1\_KRMAX (0x4092)**

Bit	7	6	5	4	3	2	1	0
Name	TIM1_KRMAX							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	TIM1_KRMAX	Max. Coefficient of Raising Edge; Range (0, 255)						

**14.3.26 TIM1\_KFMIN (0x4093)**

Bit	7	6	5	4	3	2	1	0
Name	TIM1_KFMIN							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	TIM1_KFMIN	Min. Coefficient of Falling Edge; Range (0, 255)						

**14.3.27 TIM1\_KF (0x4094, 0x4095)**

TIM1_KFH(0x4094)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_KF[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIM1_KFL(0x4095)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_KF[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM1_KF	ADC Position Detection Coefficient when floating phase voltage drops. Range [0, 32767]						

**14.3.28 TIM1\_\_KR (0x4096, 0x4097)**

TIM1_KRH(0x4096)								
Bit	15	14	13	12	11	10	9	8
Name	TIM1_KR[15:8]							
Type	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIM1_KRL(0x4097)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_KR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM1__KR	ADC Position Detection Coefficient when floating phase voltage rises Range [0, 32767]						

**14.3.29 TIM1\_\_ITRIP (0x4098, 0x4099)**

TIM1_ITRIPH(0x4098)								
Bit	15	14	13	12	11	10	9	8
Name	TIM1_ITRIP[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
TIM1_ITRIPL(0x4099)								
Bit	7	6	5	4	3	2	1	0
Name	TIM1_ITRIP[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM1__ITRIP	Filtered Bus Current When DRV_CNTR = 0, the hardware automatically samples the bus current and filters it for software application. The default channel is ADC channel 4. Range [0, 32767]  Note: The value is obtained by averaging the instantaneous current values of 8 samples.						



## 15 Timer2

### 15.1 Timer2 Instructions

Timer2 has the following five working modes:

- Output mode: PWM generation
- Input capture mode: Detect the duration of high and low level of input PWM
- Input counter mode: Detect input time of the set PWM wave numbers
- QEP & RSD mode: Quadrature Encoder Pulse & Rotating State Detection (tailwind/headwind detection) mode
- Step Mode: Detect rotation direction, position and speed of step motor.

Timer2 features:

- 3-bit programmable prescaler divides the system clock
- 16-bit up-counting Base Timer; Counting clock source serves as the output of prescaler
- 16-bit up/down-counting special timer for Input Count Mode, QEP&RSD Mode and Step Mode, with external input signal selected as clock source.
- Input filter module
- Edge detection module
- PWM generation module
- Interrupt event

#### 15.1.1 Prescaler

Prescaler divides the system clock frequency and generates clock source for Base Timer. 8 frequency division coefficients of prescaler are available and can be selected by TIM2\_CR0[T2PSC]. Since this register has no buffer, the clock source frequency is updated immediately after TIM2\_CR0[T2PSC] is written. Therefore, the frequency division coefficients shall be configured when Basic Timer is not working. The clock source frequency formula is:  $\text{clk\_psc2} = \text{SYSCLK}/(2^{\text{TIM2\_CR0[T2PSC]}})$ . The clock rate corresponding to different TIM2\_CR0[T2PSC] value as shown in Table 15-1.

Table 15-1 Mapping between Clock Rate and TIM2\_CR0[T2PSC]

TIM2_CR0[T2PSC]	Division Factor	clk_psc2(Hz)	TIM2_CR0[T2PSC]	Division Factor	clk_psc2(Hz)
000	1	24M	100	16	1.5M
001	2	12M	101	32	750k
010	4	6M	110	64	375k
011	8	3M	111	128	187.5k

#### 15.1.2 Reading, Writing and Counting of TIM2\_CNTR

When TIM2\_CR1[T2CEN] = 1, TIM2\_CNTR starts to count. The write operation to TIM2\_CNTR directly changes the value of the register, so Base Timer shall be disabled before the write operation. When

reading TIM2\_CNTR, the software reads the high-order bits first, and the hardware synchronously caches the low-order bits. When reading the low-order bits, the software reads the cached data.

### 15.1.3 Output Mode

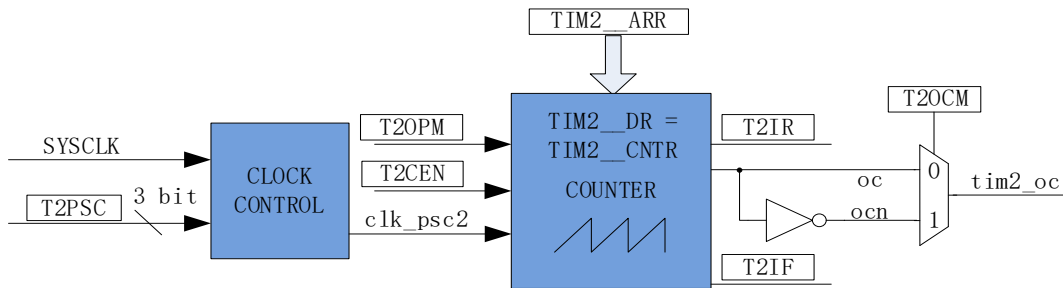


Figure 15-1 Output Mode Block Diagram

The output mode generates output signals according to TIM2\_CR0[T2OCM], and the comparison results between TIM2\_CNTR and registers TIM2\_DR, TIM2\_ARR. Meanwhile, corresponding interrupts events are generated.

#### 15.1.3.1 Reading and Writing of TIM2\_ARR/TIM2\_DR

In output mode, TIM2\_ARR/TIM2\_DR contains preload registers and shadow registers. When the software writes TIM2\_ARR/TIM2\_DR register, the data is saved in the preload register. When the overflow event TIM2\_CR1[T2IF] is generated or the Base Timer stops working (TIM2\_CR1[T2CEN] = 0), the set value is transferred to the shadow register.

TIM2\_ARR/TIM2\_DR is a 16-bit register, which requires to write the high byte first and then the low byte. The hardware ensures that the data in the preload register is not transferred to the shadow register after the high byte is written or before the low byte is written.

For example, TIM2\_DR is a preload register and DR\_SH is a shadow register. PWM is generated by comparing TIM2\_CNTR with DR\_SH. When software writes TIM2\_DR, TIM2\_DR is not updated to DR\_SH immediately, and is updated to TIM2\_DR at the end of a PWM (TIM2\_CNTR overflow event).

#### 15.1.3.2 High/Low Level Output

When TIM2\_CR0[T2OCM] = 0, if TIM2\_DR > TIM2\_ARR, the output signal is always low. When TIM2\_CR0[T2OCM] = 1, if TIM2\_DR > TIM2\_ARR, the output signal is always high.

#### 15.1.3.3 PWM Generation

In PWM generation mode, TIM2\_ARR determines PWM cycle, TIM2\_DR determines duty cycle, and duty cycle =  $TIM2\_DR / TIM2\_ARR * 100\%$ . If TIM2\_CR0[T2OCM] = 0, the low level is output when  $TIM2\_CNTR < TIM2\_DR$ , and the high level is output when  $TIM2\_CNTR \geq TIM2\_DR$ . If TIM2\_CR0[T2OCM] = 1, the high level is output when  $TIM2\_CNTR < TIM2\_DR$ , and the low level is

output when  $TIM2\_CNTR \geq TIM2\_DR$ . When  $TIM2\_CNTR$  is increased to  $TIM2\_ARR$ , the output signal is reversed.

### 15.1.3.4 Interrupts

- When  $TIM2\_CNTR = TIM2\_DR$ , a compare match event is generated and the interrupt flag bit  $TIM2\_CR1[T2IR]$  is set to “1”. The timer continues.
- When  $TIM2\_CNTR = TIM2\_ARR$ , an overflow event is generated, and the interrupt flag bit  $TIM2\_CR1[T2IF]$  is set to “1”. The timer is cleared to “0” and then restarts

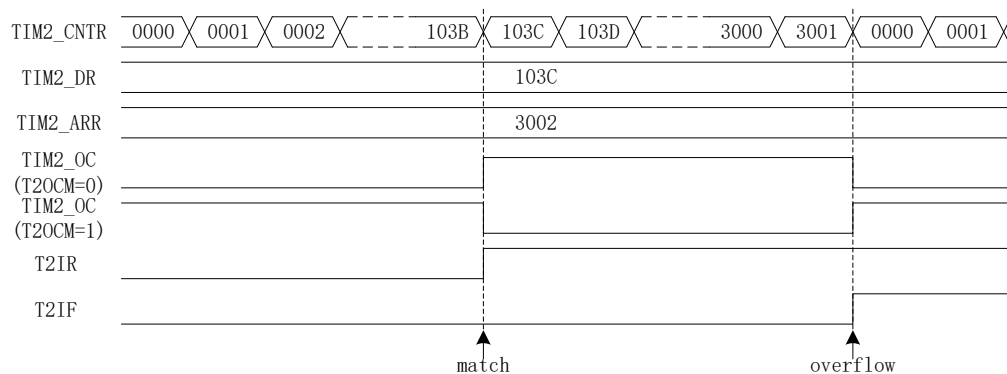


Figure 15-2 Output Mode Waveform

### 15.1.4 Input Signal Filtering and Edge Detection

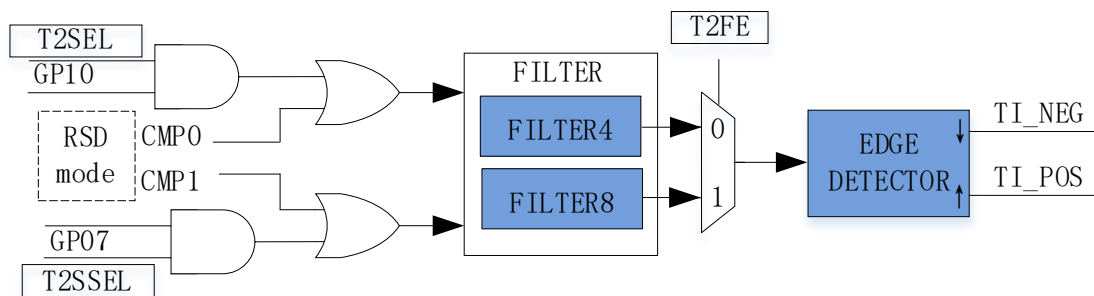


Figure 15-3 Block Diagram of Input Signal Filtering and Edge Detection

The input signal of Timer2 comes from P0.7 or P1.0, set by  $PH\_SEL[T2SEL]$  and  $PH\_SEL [T2SSEL]$  (see section 22.3.15). The filter of input signal is optional.

The filtering circuit filters out the input noise below 4/8  $SYSCCLK$  cycles. The filtering period is selected by setting  $TIM2\_CR1[T2FE]$ . When  $TIM2\_CR1[T2FE]$  is set to “0”, filtering circuit filters signals every 4 system cycles; and when  $TIM2\_CR1[T2FE]$  is set to “1”, filtering circuit filters signals every 8 system cycles. The filtered signal is 4/8 clock cycles later than the signal before filtering.  $TIM2\_CR0[T2CES]$  determines the active edge to count.

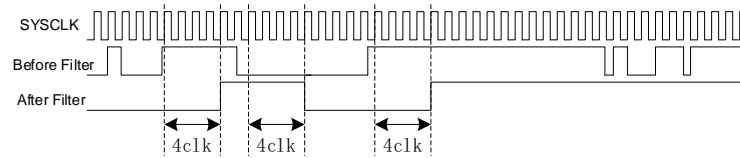


Figure 15-4 Timing Diagram of Filter Module

The edge detection module detects filtered input signals and records rising edge and falling edge for input capture mode or input counting modes.

### 15.1.5 Input Capture Mode

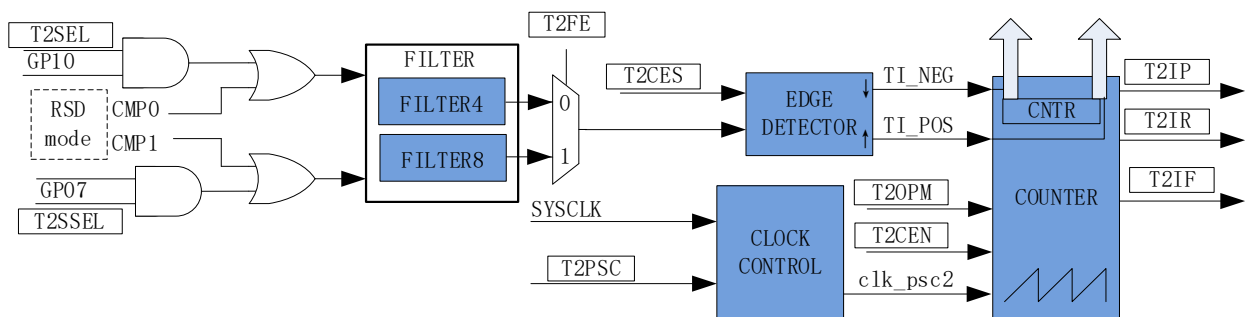


Figure 15-5 Schematic Diagram of Input Capture Mode

The input capture mode detects duty cycle and period of the PWM signal. When  $TIM\_CR0[T2CES] = 0$ , the time between two adjacent rising edges forms one cycle, and the time from rising edge to falling edge forms the pulse width (HIGH). When  $TIM\_CR0[T2CES] = 1$ , the time between two adjacent falling edges forms one cycle, and the time from falling edge to rising edge forms the pulse width (LOW). When the predefined edge arrives, the count value  $TIM2\_CNTR$  is stored in  $TIM2\_DR$  and  $TIM2\_ARR$  respectively to calculate the period and duty cycle of PWM waveform.

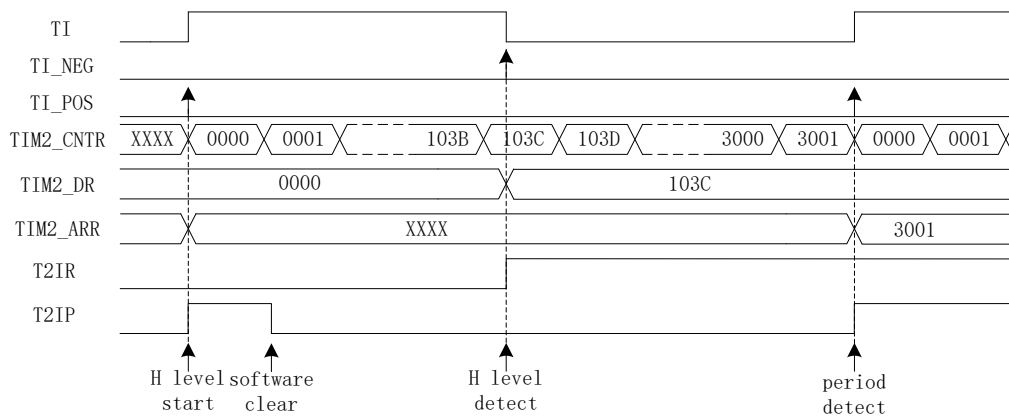


Figure 15-6 Timing Diagram of Input Capture Mode ( $TIM2\_CR0[T2CES] = 0$ )

For example, when  $TIM2\_CR0[T2CES] = 0$ ,  $TIM2\_CR1[T2CEN]$  is set to “1” to enable the Base Timer. When the first rising edge of the input (falling edge is invalid) is detected,  $TIM2\_CNTR$  is cleared and restarts. When falling edge of the input is detected, the value of  $TIM2\_CNTR$  is stored in  $TIM2\_DR$ , while the interrupt flag  $TIM2\_CR1[T2IR]$  is set to “1”, and  $TIM2\_CNTR$  continues to count. When the second rising edge of input is detected, the value of  $TIM2\_CNTR$  is stored in  $TIM2\_ARR$ . Meanwhile, the interrupt flag  $TIM2\_CR1[T2IP]$  is set to “1”, and  $TIM2\_CNTR$  is cleared to “0” and restarts.

An overflow event occurs if Timer2 does not detect the second rising edge of the input and  $TIM2\_CNTR$  reaches 0xFFFF. In this case, the interrupt flag  $TIM2\_CR1[T2IF]$  is set to “1”, and  $TIM2\_CNTR$  is cleared to “0” and restarts. At this point,  $TIM2\_ARR$  value is 0xFFFF, and the  $TIM2\_DR$  value is determined by the input level and  $TIM2\_CR0[T2OCM]$  XOR.

### 15.1.6 Input Counter Mode

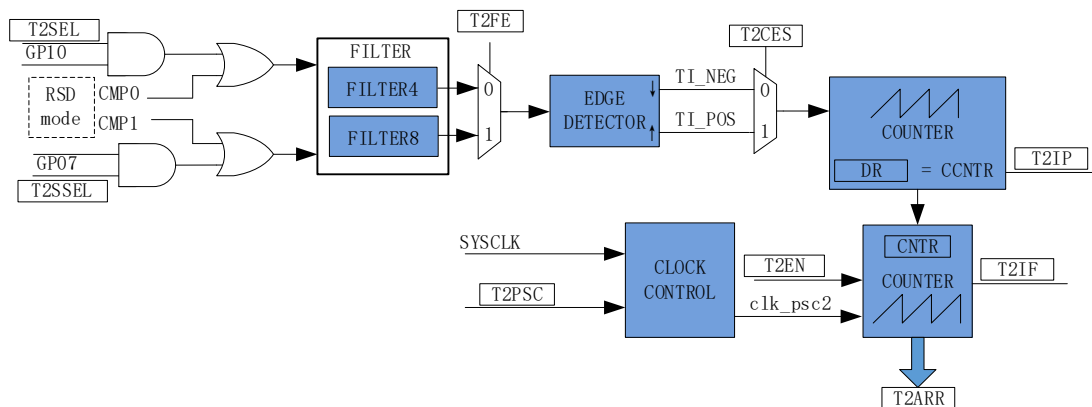


Figure 15-7 Schematic Diagram of Input Counter Mode

In input counter mode,  $TIM2\_DR$  includes preload register and shadow register. When the software writes  $TIM2\_DR$  register, the data is saved in the preload register first, and then sent to the shadow register in case of compare match event ( $TIM2\_CR1[T2IP] = 1$ ), overflow event ( $TIM2\_CR1[T2IF] = 1$ ) or special timer disable ( $TIM2\_CR1[T2CEN] = 0$ ).  $TIM2\_DR$  is a 16-bit register, which requires the software writes the high-order byte first and then the low-order byte. The hardware ensures that the data in the preload register is not updated to the shadow register after the high-order byte is written and before the low-order byte is written.

The input counter mode is used to detect the time to input the set PWM wave. When the number of input PWM counted by the special timer  $CCNTR$  reaches the set value ( $TIM2\_DR$ ),  $TIM2\_CNTR$  of the Base Timer is stored in  $TIM2\_ARR$ . When  $TIM2\_CR0[T2CES]$  is set to “1”, the rising edge of the input PWM signal serves as the active counting edge of the special timer; when  $TIM2\_CR0[T2CES]$  is set to “0”, the falling edge of the input signal as the active edge.

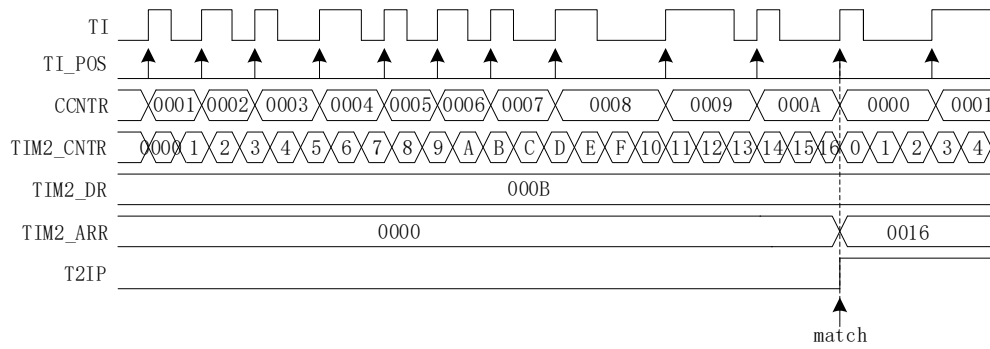


Figure 15-8 Timing Diagram of Input Counter Mode

The Basic Timer is enabled when TIM2\_CR1[T2CEN] is set to “1”. If the first active edge of the input signal is detected, TIM2\_CNTR is cleared to “0” and restarts. Whenever active edge of the input signal arrives, one is added to the count value of the special timer CCNTR. When the count value reaches TIM2\_DR, TIM2\_CNTR is stored in TIM2\_ARR. When TIM2\_CR1[T2IP] is set to “1”, TIM2\_CNTR and CCNTR are cleared to “0” and restart.

When the number of input PWM does not reach the set value and TIM2\_CNTR reaches 0xFFFF, an overflow event generates, and the interrupt flag TIM2\_CR1[T2IF] is set to “1”. TIM2\_CNTR is cleared to “0” with CCNTR uncleared. TIM2\_CNTR starts counting from 0, and CCNTR continues counting with the previous value.

### 15.1.7 QEP&RSD Mode

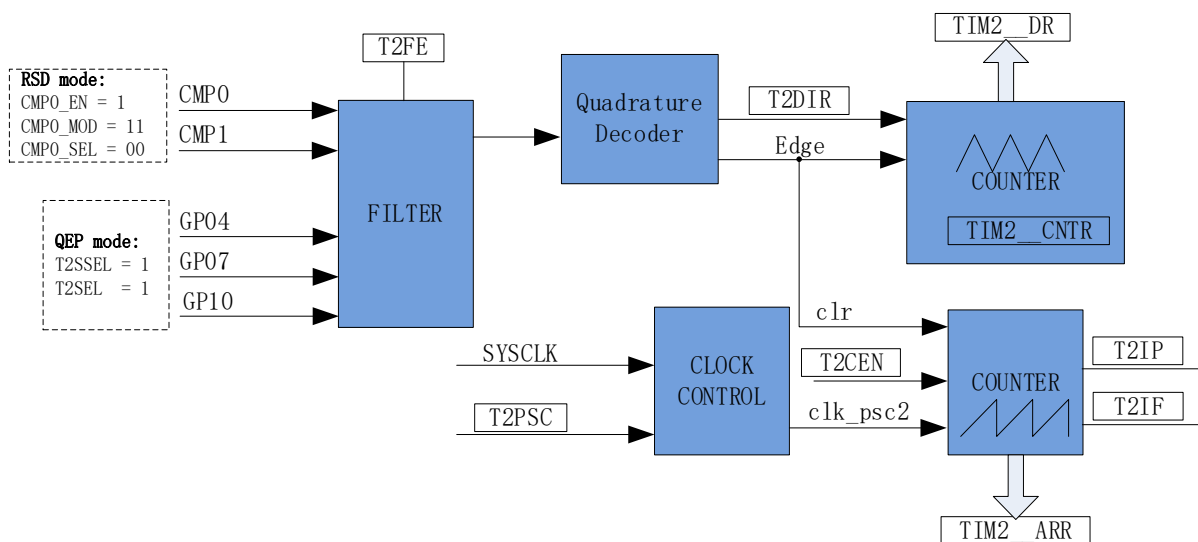


Figure 15-9 Schematic Diagram of QEP&RSD Mode

QEP & RSD mode obtains relative position, direction and speed of the motor by detecting orthogonal signals on two channels. P0.7 and P1.0 (QEP mode) or CMP0, CMP1 (RSD mode) are the input signal

sources, which are sent to the quadrature decoding module from the filtering module to obtain active edge and direction (TIM2\_CR1[T2DIR]).

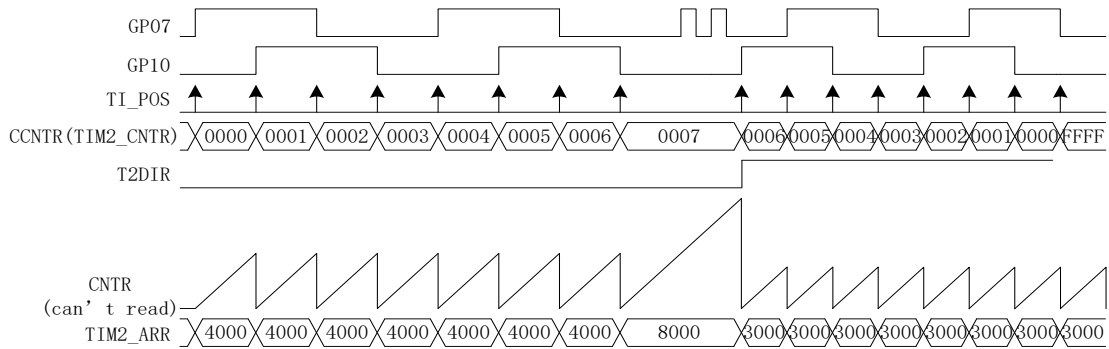


Figure 15-10 Timing Diagram of QEP&RSD Mode

The special timer is an up/down counter, and the signal source is the active edge from orthogonal decoding module. If TIM2\_CR1[T2DIR] = 0, the direction is positive, and special timer counts upward. When the active edge arrives, the timer increases by one. If TIM2\_CR1[T2DIR] = 1, the direction is reverse and special timer counts down. When the active edge arrives, the timer decreases by one. In QEP Mode, after configuring the code value held in TIM2\_DR, the count-up timer is cleared to “0” and restarts when it reaches TIM2\_DR, and the count-down timer is reloaded with TIM2\_DR when it decrements up to 0. The mechanical zero signal (“Z signal”) of QEP encoder is input from P0.4 and generates the TIM2\_CR1[T2IR] interrupt event flag.

The Base Timer is an up-counter used to record the time of two active counting edges. The clock source frequency can be divided. When the counting edge arrives, the value of Base Timer is stored in TIM2\_ARR and cleared to “0”, and TIM2\_CR1[T2IP] interrupt flag bit is set to “1”. When Base Timer counts to 0xFFFF, the count overflows and TIM2\_CR1[T2IF] interrupt flag is generated.

### 15.1.7.1 RSD Comparator Sampling

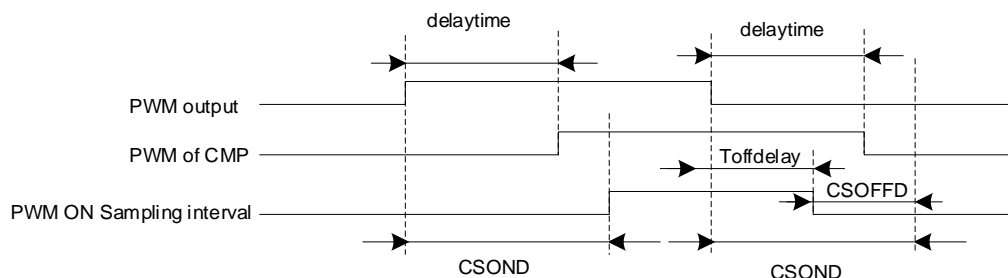


Figure 15-11 PWM ON Sampling Mode

The Start of Sampling (“SoS”) time delay and End of Sampling (“EoS”) time advance must be set in

order to sample correct BEMF comparison signals in RSD Sampling mode.

See section 29.1.5 for details.

### 15.1.8 Step Mode

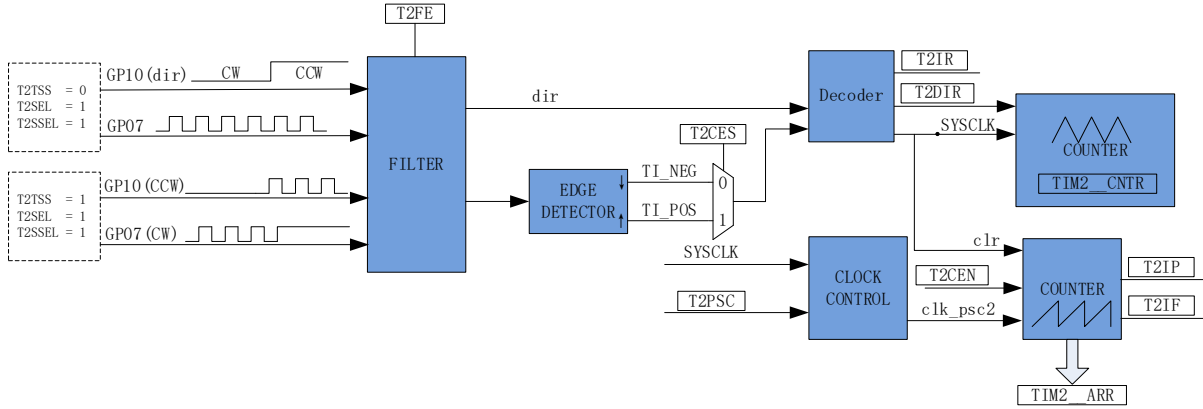


Figure 15-12 Step Mode Schematic Diagram

In step mode, relative position, direction and speed of the step motor are obtained by detecting inputs of the two channel. P1.0 is direction input, and P0.7 is pulse input. Setting TIM2\_CR0[T2CES] to select the rising edge or falling edge as the active edge. The input signals are sent to decoding module from the filtering module to obtain the active edge and direction TIM2\_CR1[T2DIR].

Note: TIM2\_CR1[T2DIR] will not change unless transition occurs at P1.0 and active edge is detected at P0.7. To generate an interrupt immediately after P1.0 changes, use INT1.

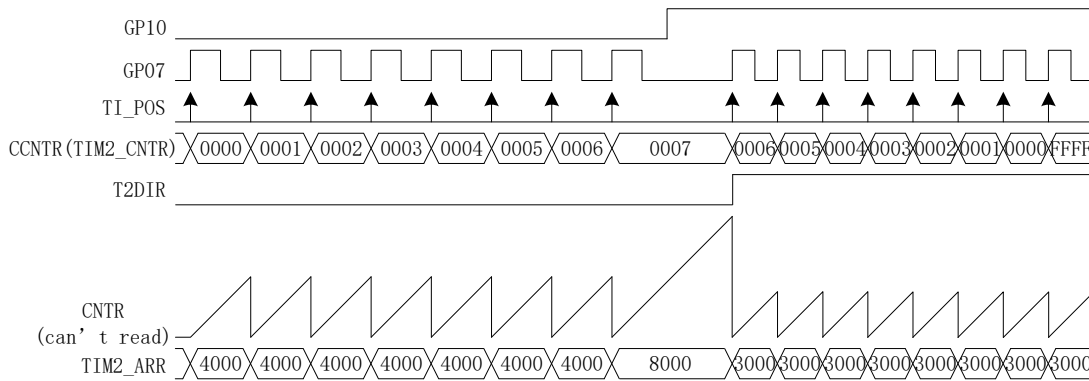


Figure 15-13 Timing Diagram of Step Mode





## 15.2 Timer2 Registers

### 15.2.1 TIM2\_CR0 (0xA1)

Bit	7	6	5	4	3	2	1	0
Name	T2PSC			T2OCM	T2IRE	T2CES	T2MOD	
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:5]	T2PSC	Base Timer Clock Prescaler Select Bit It is configured to divide the system clock frequency and generate the clock source for Base Timer. The prescaled clock rates are configured as follows: 000: 24MHz      001: 12MHz 010: 6MHz        011: 3MHz 100: 1.5MHz     101: 750kHz 110: 375kHz     111: 187.5kHz						
[4]	T2OCM	Output Mode: Output Mode Select Bit 0: Output “0” when TIM2_CNTR < TIM2_DR; output “1” when TIM2_CNTR ≥ TIM2_DR 1: Output “1” when TIM2_CNTR < TIM2_DR; output “0” when TIM2_CNTR ≥ TIM2_DR Input Count Mode: No effect Input Capture Mode: TIM2_DR indicates the input level to be selected when timer TIM2_CNTR becomes overflowed. 0: TIM2_DR is reset to “0” by hardware for low-level input upon an overflow interrupt and is set to “0xFFFF” for high-level input upon an overflow interrupt. 1: TIM2_DR is reset to “0” by hardware for high-level input upon an overflow interrupt and is set to “0xFFFF” for low-level output upon an overflow interrupt. QEP&RSD Mode and Step Mode Select Bit 0: QEP&RSD Mode 1: Step Mode						
[3]	T2IRE	Output Mode: Match Interrupt Enable Input Capture Mode: Pulse Width Detection Interrupt Enable Input Count Mode: No effect QEP Mode: QEP Encoder Z Signal Interrupt Enable Step Mode: No effect 0: Disable 1: Enable						
[2]	T2CES	Output Mode: No effect Input Capture Mode: Counting Edge Select Bit 0: The time between two adjacent raising edges forms one cycle, and the time from rising edge to falling edge forms the pulse width (HIGH). The time between two adjacent falling edges forms one cycle, and the time from falling edge to raising edge forms the pulse width (LOW). Input Count Mode: Active Edge Select Bit 0: Falling Edge Count 1: Raising Edge Count QEP&RSD Mode: Enable Pulse Counter Cleared upon Z Signal Interrupt INT1 0: Disable 1: Enable Step Mode: Active Edge Select Bit 0: Falling Edge Count 1: Raising Edge Count						
[1:0]	T2MOD	Mode Select Bit 00: Input Capture Mode 01: Output Mode 10: Input Count Mode 11: QEP&RSD Mode or Step Mode						

**15.2.2 TIM2\_CR1 (0xA9)**

Bit	7	6	5	4	3	2	1	0
Name	T2IR	T2IP	T2IF	T2IPE	T2IFE	T2FE	T2DIR	T2CEN
Type	R/W0	R/W0	R/W0	R/W	R/W	R/W	R	R/W
Reset	0	0	0	0	0	0	-	0
Bit	Name	Description						
[7]	T2IR	Output Mode: Match Interrupt Flag Input Capture Mode: Pulse Width Detection Interrupt Flag Input Count Mode: No effect QEP Mode: QEP Encoder Z Signal Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect						
[6]	T2IP	Output Mode: No effect Input Capture Mode: PWM Cycle Detection Interrupt Flag Input Count Mode: PWM Input Count Match Interrupt Flag QEP&RSD Mode and Step Mode: Active Edge Detection Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect						
[5]	T2IF	Output Mode: Base Timer Overflow Interrupt Flag, which is set to “1” when TIM2_CNTR matches TIM2_ARR. Input Capture Mode: Base Timer Overflow Interrupt Flag, which is set to “1” when the Timer has not detected an input PWM cycle but the timer TIM2_CNTR value reaches 0xFFFF. Input Count Mode: Special-purpose timer overflow Interrupt Flag, which is set to “1” when the input PWM cycle has not reached the preset TIM2_DR value but the Base Timer TIM2_CNTR value reaches 0xFFFF. QEP&RSD Mode and Step Mode: Base Timer Overflow Interrupt Flag, which is set to “1” and Basic Timer is cleared to “0” when Basic Timer reaches to 0xFFFF. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: No effect						
[4]	T2IPE	Output Mode: No effect Input Capture Mode: PWM Cycle Detection Interrupt Enable Input Count Mode: PWM Input Count Match Interrupt Enable QEP&RSD Mode and Step Mode: Active Edge Detection Interrupt Enable 0: Disable 1: Enable						
[3]	T2IFE	Output Mode: Base Timer Overflow Interrupt Enable Input Capture Mode: Base Timer Overflow Interrupt Enable Input Count Mode: Base Timer Overflow Interrupt Enable QEP&RSD Mode and Step Mode: Base Timer Overflow Interrupt Enable 0: Disable 1: Enable						
[2]	T2FE	Input Signal Filter Select Bit Input signals are filtered out as noise if the pulse width is less than 4/8 clock cycle.						

		Assuming that the system clock runs at 24MHz (41.67ns) , then the pulse width for filtering is 166.67/333.34ns. 0: Signals filtered on every 4 clock cycles 1: Signals filtered on every 8 clock cycles
[1]	T2DIR	QEP&RSD Mode: Indicator of Motor Rotation Direction Rotation direction of the motor is determined according to the phase relationship of the two input signals. Step Mode: Indicator of Motor Rotation Direction Rotation direction of the motor is determined according to the direction signal P1.0. 0: Forward 1: Backward
[0]	T2CEN	Base Timer Enable 0: Disable 1: Enable

### 15.2.3 TIM2\_\_CNTR (0xAA, 0xAB)

TIM2__CNTRH(0xAB)								
Bit	15	14	13	12	11	10	9	8
Name	TIM2__CNTR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIM2__CNTRL(0xAA)								
Bit	7	6	5	4	3	2	1	0
Name	TIM2__CNTR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM2__CNTR	Output Mode/Input Capture Mode/Input Count Mode: Count values held in the Base Timer QEP&RSD Mode and Step Mode: count values held in the special timer						

### 15.2.4 TIM2\_\_DR (0xAC, 0xAD)

TIM2__DRH(0xAD)								
Bit	15	14	13	12	11	10	9	8
Name	TIM2__DR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIM2__DRL(0xAC)								
Bit	7	6	5	4	3	2	1	0
Name	TIM2__DR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM2__DR	Output Mode: Compare match value (written by software) Input Capture Mode: Count value of the detected input pulse width (written by hardware) Input Count Mode: PWM cycles to be counted (written by software) QEP Mode: Encoder value Step Mode: No effect						

**15.2.5 TIM2\_\_ARR (0xAE, 0xAF)**

TIM2__ARRH(0xAF)								
Bit	15	14	13	12	11	10	9	8
Name	TIM2__ARR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIM2__ARRL(0xAE)								
Bit	7	6	5	4	3	2	1	0
Name	TIM2__ARR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIM2__ARR	Output Mode: PWM cycle (written by software) Input Capture Mode: Count value held in Base Timer of a PWM cycle (written by hardware) Input Count Mode: Count value held in Base Timer when the input PWM count matches (written by hardware) QEP&RSD Mode and Step Mode: Count value held in Base Timer when the input signal is detected as an active edge (written by hardware)						

## 16 Timer3/Timer4

### 16.1 Timer3/Timer4 Instructions

Timer3/Timer4 support output and input modes:

- Output mode: Generate PWM
- Input capture mode: Detect the duration of high and low level of input PWM, which can be used to calculate PWM duty cycle

Timer3/Timer4 Features:

- 3-bit programmable prescaler divides system clock as the clock source for Base Timer (clock source of Timer3 can be doubled to 48MHz in input capture mode)
- 16-bit up-counting Base Timer; The output of the prescaler serves as the counting clock source
- Input signal filtering
- Input signal edge detection
- Output PWM signal, single compare output
- Interrupt event

#### 16.1.1 Prescaler

Prescaler divides the system clock frequency and generates counter clock source for Base Timer. 8 frequency division coefficients of prescaler are available and can be selected by TIMx\_CR0[TxPSC]. Since this register has no buffer, the clock source frequency is updated immediately after TIMx\_CR0[TxPSC] is written. Therefore, the frequency division coefficients shall be configured when Basic Timer is not working. The clock source frequency formula is:  $clk\_psc_x = SYSCLK / (2^{TxPSC})$ . The clock rate corresponding to different TIMx\_CR0[TxPSC] value as shown in Table 16-1.

Table 16-1 Mapping between Clock Rate and TIMx\_CR0[TxPSC]

TIMx_CR0[TxPSC]	Division Factor	clk_pscx(Hz)	TIMx_CR0[TxPSC]	Division Factor	clk_pscx(Hz)
000	0x1	24M	100	0x10	1.5M
001	0x2	12M	101	0x20	750k
010	0x4	6M	110	0x40	375k
011	0x8	3M	111	0x80	187.5k

Note: In Input Capture Mode of Timer3, the clock rate is 48MHz when TIM3\_CR0[T3PSC] = 111.

#### 16.1.2 Reading, Writing and Counting of TIMx\_CNTR

TIMx\_CNTR starts when TIMx\_CR1[TxEN] = 1. The write operation to TIMx\_CNTR directly changes the value of the register, so it is required to disable the timer before the write operation. When reading TIMx\_CNTR, the software reads high-order bits first and then low-order bits, and the hardware caches the low-order bits simultaneously. When reading the low-order bits, the software reads the cached data.

### 16.1.3 Output Mode

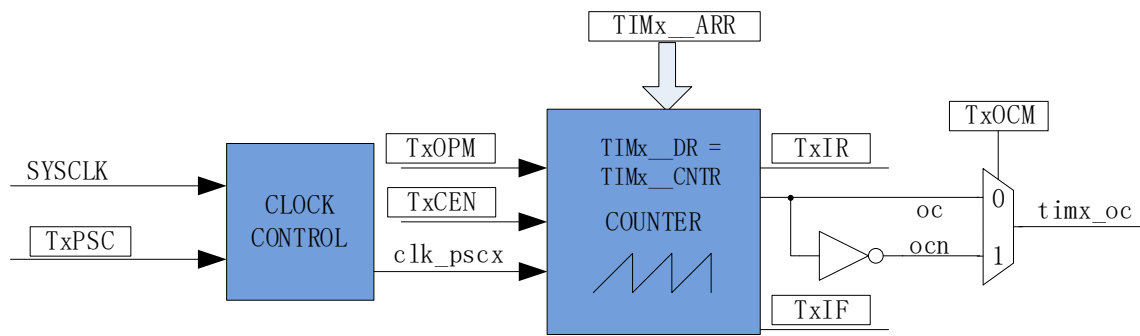


Figure 16-1 Output Mode Block Diagram

The output mode generate output signals according to  $TIMx\_CR0[TxOCM]$ , and the comparison results between  $TIMx\_CNTR$  and registers  $TIMx\_DR$ ,  $TIMx\_ARR$ . Meanwhile, corresponding interrupts is generated.

#### 16.1.3.1 High-/Low-level Output Mode

When  $TIMx\_CR0[TxOCM] = 0$  and  $TIMx\_DR > TIMx\_ARR$ , the output signals are always low. When  $TIMx\_CR0[TxOCM] = 1$  and  $TIMx\_DR > TIMx\_ARR$ , the output signals are always high.

#### 16.1.3.2 PWM Generation

In PWM generation mode,  $TIMx\_ARR$  determines PWM cycle, and  $TIMx\_DR$  determines the duty cycle, and  $duty\ cycle = TIMx\_DR / TIMx\_ARR * 100\%$ . If  $TIMx\_CR0[TxOCM] = 0$ , the low level is output when  $TIMx\_CNTR < TIMx\_DR$ , and the high level is output when  $TIMx\_CNTR \geq TIMx\_DR$ . If  $TIMx\_CR0[TxOCM] = 1$ , the high level is output when  $TIMx\_CNTR < TIMx\_DR$ , and low level is output when  $TIMx\_CNTR \geq TIMx\_DR$ . When  $TIMx\_CNTR > TIMx\_ARR$ , the output signal is reversed.

#### 16.1.3.3 Interrupt Event

- When  $TIMx\_CNTR = TIMx\_DR$ , a compare match interrupt is generated. The interrupt flag  $TIMx\_CR1[TxIR]$  is set to “1”, and the timer continues.
- When  $TIMx\_CNTR = TIMx\_ARR$ , an overflow event is generated. The interrupt flag  $TIMx\_CR1[TxIF]$  is set to “1”, and the timer is cleared to “0”.  $TIMx\_CR0[TxOPM]$  determines whether the timer recounts. The timer stops when  $TIMx\_CR0[TxOPM] = 1$ , and restarts when  $TIMx\_CR0[TxOPM] = 0$ .

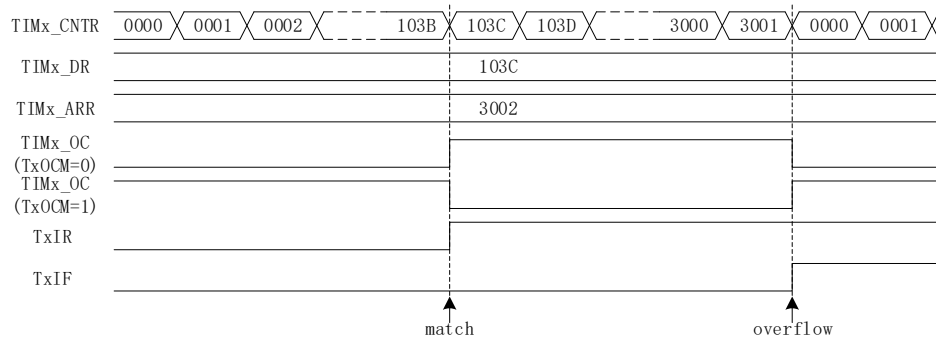


Figure 16-2 Output Waveform of Output Mode

### 16.1.4 Input Signal Filtering and Edge Detection

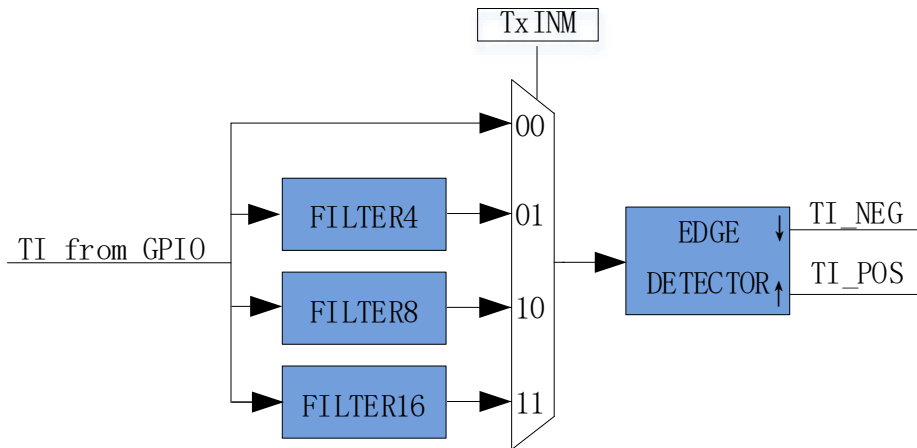


Figure 16-3 Block Diagram of Input Signal Filtering and Edge Detection

The input signals of Timer3/Timer4 come from GPIO pin. TIMx\_CR1[TxINM] is configured to disable the filtering circuit or filter out the input noise below 4/8/16 system clock cycles. The filtered signal is 4/8/16 system clock cycles delayed than the signal before filtering.

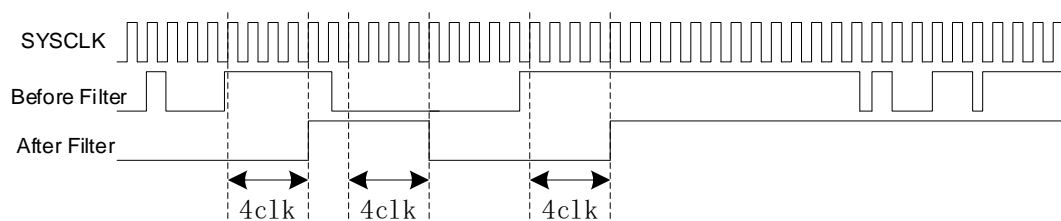


Figure 16-4 Timing Diagram of Filter Module

The edge detection module detects the filtered input signal from filtering module, and records the rising edge and falling edge for input capture mode.



### 16.1.5 Input Capture Mode

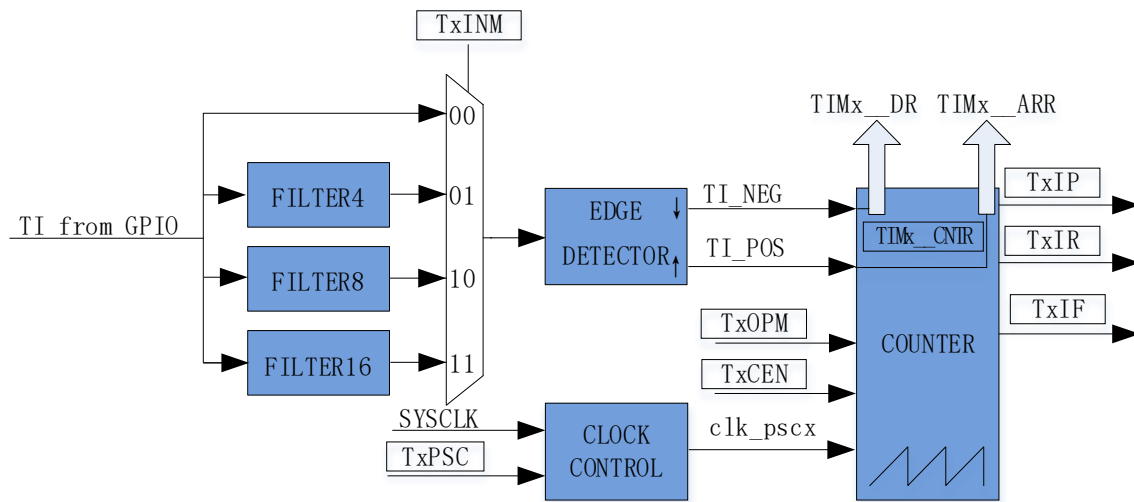


Figure 16-5 Schematic Diagram of Input Capture Mode

The Input Capture Mode detects pulse width and waveform period of the input PWM signals. When  $TIMx\_CR0[TxOCM] = 0$ , the time between two adjacent rising edges forms one cycle, and the time from rising edge to falling edge forms the pulse width (HIGH). When  $TIMx\_CR0[TxOCM] = 1$ , the time between two adjacent falling edges forms one cycle, and the time from falling edge to rising edge forms the pulse width (LOW). The pulse width and the period obtained by  $TIMx\_CNTR$  are stored in  $TIMx\_DR$  and  $TIMx\_ARR$  respectively.

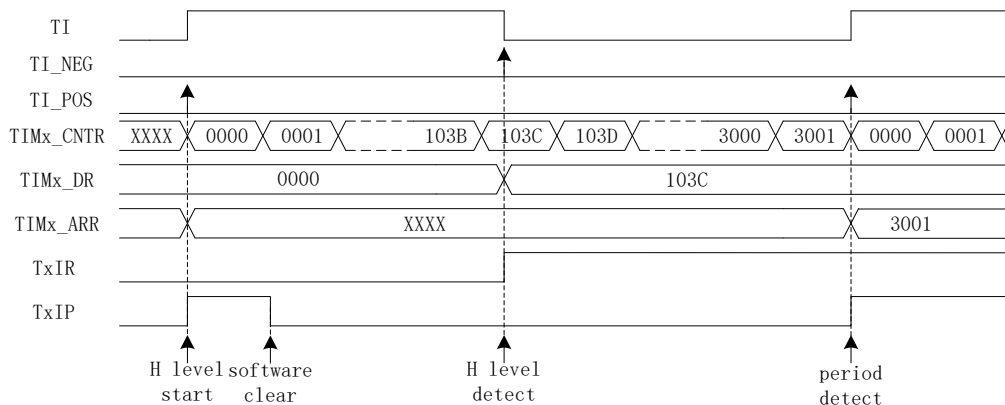


Figure 16-6 Timing Diagram of Input Capture Mode ( $TIMx\_CR0[TxOCM] = 0$ )

For example, when  $TIMx\_CR0[TxOCM] = 0$ ,  $TIMx\_CR1[TxEN]$  is set to “1” to enable the timer. The Base Timer is cleared to “0” and restarts when the first raising edge is detected. When the falling edge is detected, the value of  $TIMx\_CNTR$  is stored into  $TIMx\_DR$ . Meanwhile, the interrupt flag  $TIMx\_CR1[TxIR]$  is set to “1”, and  $TIMx\_CNTR$  continues to count. When the second rising edge is detected, the value of  $TIMx\_CNTR$  is saved into  $TIMx\_ARR$ . The interrupt flag  $TIMx\_CR1[TxIP]$  is set

to “1” and TIMx\_CNTR is cleared to “0”. TIMx\_CR0[TxOPM] determines whether the timer restarts. If TIMx\_CR0[TxOPM] = 1, the timer stops; and if TIMx\_CR0[TxOPM] = 0, it restarts.

An overflow event occurs if Timer3/Timer4 does not detect the second rising edge of the input and TIMx\_CNTR reaches 0xFFFF. In this case, the interrupt flag bit TIMx\_CR1[TxIF] is set to “1”, and TIMx\_CNTR is cleared to “0”. TIMx\_CR0[TxOPM] determines whether the timer restarts. If TIMx\_CR0[TxOCM]= 1, the timer stops counting, and if TIMx\_CR0[TxOPM] = 0, it restarts. At this point, TIMx\_ARR is 0xFFFF, and TIMx\_DR is determined by the input level and TIMx\_CR0[TxOCM] XOR.

### 16.1.6 Timer4 FG Output Mode

See FG Output Generation for details.

## 16.2 Timer3/Timer4 Registers

### 16.2.1 TIMx\_CR0 (0x9C/0x9E) (x = 3/4)

Bit	7	6	5	4	3	2	1	0
Name	TxPSC			TxOCM	TxIRE	RSV	TxOPM	TxMOD
Type	R/W	R/W	R/W	R/W	R/W	-	R/W	R/W
Reset	0	0	0	0	0	-	0	0
Bit	Name	Description						
[7:5]	TxPSC	Base Timer Clock Prescaler Select Bit It is configured to divide the system clock frequency and generate the clock source for Base Timer. The prescaled clock rates are configured as follows: 000: 24MHz 001: 12MHz 010: 6MHz 011: 3MHz 100: 1.5MHz 101: 750kHz 110: 375kHz 111: 187.5kHz Note: In Input Capture Mode of Timer3, the clock rate is 48MHz when the bit is set to “111”.						
[4]	TxOCM	Output Mode: Output Mode Selection 0: Output “0” when TIMx_CNTR < TIMx_DR; output “1” when TIMx_CNTR ≥ TIMx_DR 1: Output “1” when TIMx_CNTR < TIMx_DR; output “0” when TIMx_CNTR ≥ TIMx_DR Input Capture Mode: TIMx_DR indicates the input level to be selected when the active edge is detected or the timer becomes overflowed. Active Edge Selection 0: The time between two adjacent raising edges forms one cycle, and the time from rising edge to falling edge forms the pulse width (HIGH). 1: The time between two adjacent falling edges forms one cycle, and the time from falling edge to raising edge forms the pulse width (LOW). TIMx_DR indicates the input level to be selected when the timer becomes overflowed. 0: TIMx_DR is reset to “0” by hardware for low-level input upon an overflow interrupt and is set to “0xFFFF” by hardware for high-level input upon an overflow interrupt. 1: TIMx_DR is reset to “0” by hardware for high-level input upon an overflow interrupt and is set to “0xFFFF” for low-level input upon an overflow interrupt.						
[3]	TxIRE	Output Mode: Compare Match Interrupt Enable Input Capture Mode: Pulse Width Detection Interrupt Enable 0: Disable 1: Enable						
[2]	RSV	Reserved						

[1]	TxOPM	Single Mode Base Timer stops in any of the following events: Output Mode: Base Timer overflow event Input Capture Mode: PWM Cycle Detection or Base Timer overflow event 0: Base Timer does not stop 1: Base Timer stops (TIMx_CR1[TxEN] is reset to “0”)
[0]	TxMOD	Working Mode Selection 0: Input Capture Mode 1: Output Mode

### 16.2.2 TIMx\_CR1 (0x9D/0x9F) (x = 3/4)

Bit	7	6	5	4	3	2	1	0
Name	TxIR	TxIP	TxIF	TxIPE	TxIFE	TxINM		TxEN
Type	R/W0	R/W0	R/W0	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[7]	TxIR	Output Mode: Compare Match Interrupt Flag Input Capture Mode: Pulse Width Detection Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect
[6]	TxIP	Output Mode: No effect Input Capture Mode: PWM Cycle Detection Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect
[5]	TxIF	Output Mode: Base Timer Overflow Interrupt Flag, which is set to “1” when TIMx_CNTR matches TIMx_ARR. Input Capture Mode: Base Timer Overflow Interrupt Flag, which is set to “1” when the Timer does not detect an input PWM cycle but TIMx_CNTR reaches 0xFFFF. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect
[4]	TxIPE	Output Mode: No effect Input Capture Mode: PWM Cycle Detection Interrupt Enable 0: Disable 1: Enable
[3]	TxIFE	Output Mode: Base Timer Overflow Interrupt Input Capture Mode: Base Timer Overflow Interrupt Enable 0: Disable 1: Enable
[2:1]	TxINM	Input Signal Filtering Pulse Width Select Bit Input signals are filtered as noise if pulse width is less than the defined value. 00: Not to filter signals 01: Filtered on every 4 SYSCLK cycles 10: Filtered on every 8 SYSCLK cycles 11: Filtered on every 16 SYSCLK cycles

[0]	TxEN	Base Timer Enable 0: Disable 1: Enable
-----	------	--

### 16.2.3 TIMx\_CNTR (0xA2, 0xA3/0x92, 0x93) (x = 3/4)

TIMx_CNTRH(0xA3/0x93)								
Bit	15	14	13	12	11	10	9	8
Name	TIMx_CNTR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIMx_CNTRL(0xA2/0x92)								
Bit	7	6	5	4	3	2	1	0
Name	TIMx_CNTR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIMx_CNTR	Count values held in Base Timer						

### 16.2.4 TIMx\_DR (0xA4, 0xA5/0x94, 0x95) (x = 3/4)

TIMx_DRH(0xA5/0x95)								
Bit	15	14	13	12	11	10	9	8
Name	TIMx_DR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIMx_DRL(0xA4/0x94)								
Bit	7	6	5	4	3	2	1	0
Name	TIMx_DR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	TIMx_DR	Output Mode: Compare match values (written by software) Input Capture Mode: Count value of the detected input pulse width (written by hardware)						

### 16.2.5 TIMx\_ARR (0xA6, 0xA7/0x96, 0x97) (x = 3/4)

TIMx_ARRH(0xA7/0x97)								
Bit	15	14	13	12	11	10	9	8
Name	TIMx_ARR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
TIMx_ARRL(0xA6/0x96)								
Bit	7	6	5	4	3	2	1	0
Name	TIMx_ARR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[15:0]	TIMx_ARR	Output Mode: Reload value (written by hardware) See FG Output Generation for details. Input Capture Mode: Count value of a detected PWM cycle (written by hardware)

## 17 Systick

### 17.1 Systick Instructions

The chip can generate Systick interrupts at a fixed interval, and the interrupt cycle is controlled by SYST\_ARR. Systick interrupt is enabled when DRV\_SR[SYSTIE] is set to “1”, and the interrupts are accessed by P10.

### 17.2 Systick Registers

#### 17.2.1 DRV\_SR (0x4061)

Bit	7	6	5	4	3	2	1	0
Name	SYSTIF	SYSTIE	FGIF	DCIF	FGIE	DCIP	DCIM	
Type	R/W0	R/W	R/W0	R/W0	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[7]	SYSTIF	Systick Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect
[6]	SYSTIE	Systick Interrupt Enable 0: Disable 1: Enable
[5]	FGIF	FG Interrupt Flag When FOC Drive/Square Wave Drive is enabled, an FGIF Interrupt is generated in each rotation cycle (electrical cycle). Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect
[4]	DCIF	Driver Match Interrupt Flag When the Driver counter value is equal to DRV_COMR, the system decides whether to generate an interrupt according to the counting direction set by DRV_SR[DCIM]. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect
[3]	FGIE	FG Interrupt Enable When FOC Drive/Square Wave Drive is enabled, an FG Interrupt is generated in each rotation cycle (electrical cycle). 0: Disable 1: Enable
[2]	DCIP	Number of PWM cycles required to generate a Driver Match Interrupt 0: 1 interrupt in 1 PWM cycle 1: 1 interrupt in 2 PWM cycles
[1:0]	DCIM	Driver Match Interrupt Mode Select Bit The system decides whether to generate an interrupt according to DRV_SR[DCIM]

		when Driver counter value is equal to DRV_COMR value. 00: No interrupt is generated. 01: An interrupt is generated when the counter counts up 10: An interrupt is generated when the counter counts down 11: An interrupt is generated when the counter counts up/down
--	--	--

**17.2.2 SYST\_ARR (0x4064, 0x4065)**

SYST_ARRH(0x4064)								
Bit	15	14	13	12	11	10	9	8
Name	SYST_ARR[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	1	0	1	1	1	0	1
SYST_ARRL(0x4065)								
Bit	7	6	5	4	3	2	1	0
Name	SYST_ARR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	1	0	1	1	1	1	1	1
Bit	Name	Description						
[15:0]	SYST_ARR	Systick Reloaded Value This bit determines the cycle at which Systick interrupts are generated, which defaults to 1ms. Calculation formula is as follows: Systick interrupt rate = $\text{SYSCLK}/(\text{SYST\_ARR}[15:0] + 1)$ Range [0, 65535]						

## 18 Driver

### 18.1 Driver Instructions

#### 18.1.1 Driver Introduction

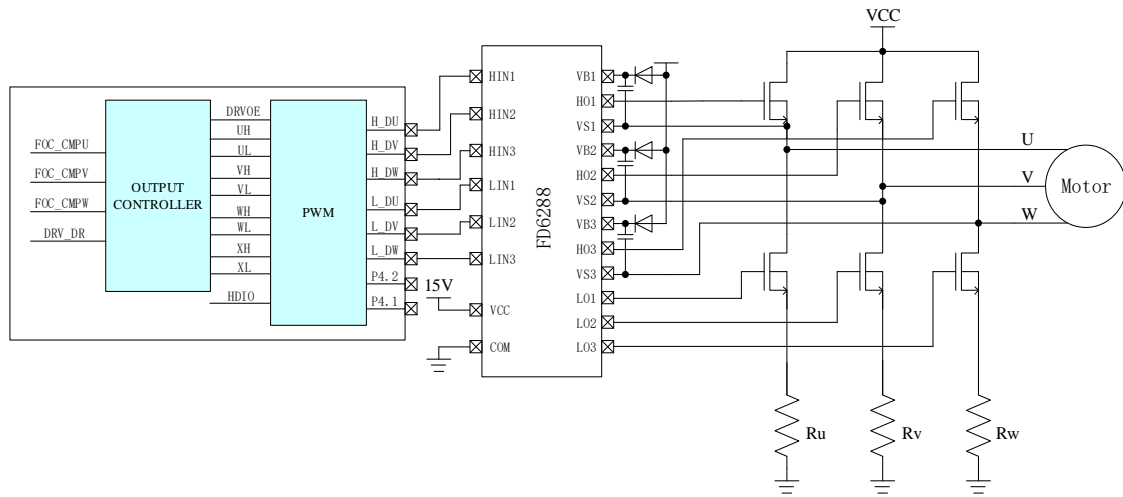


Figure 18-1 Block Diagram of FU6815L Driver Module

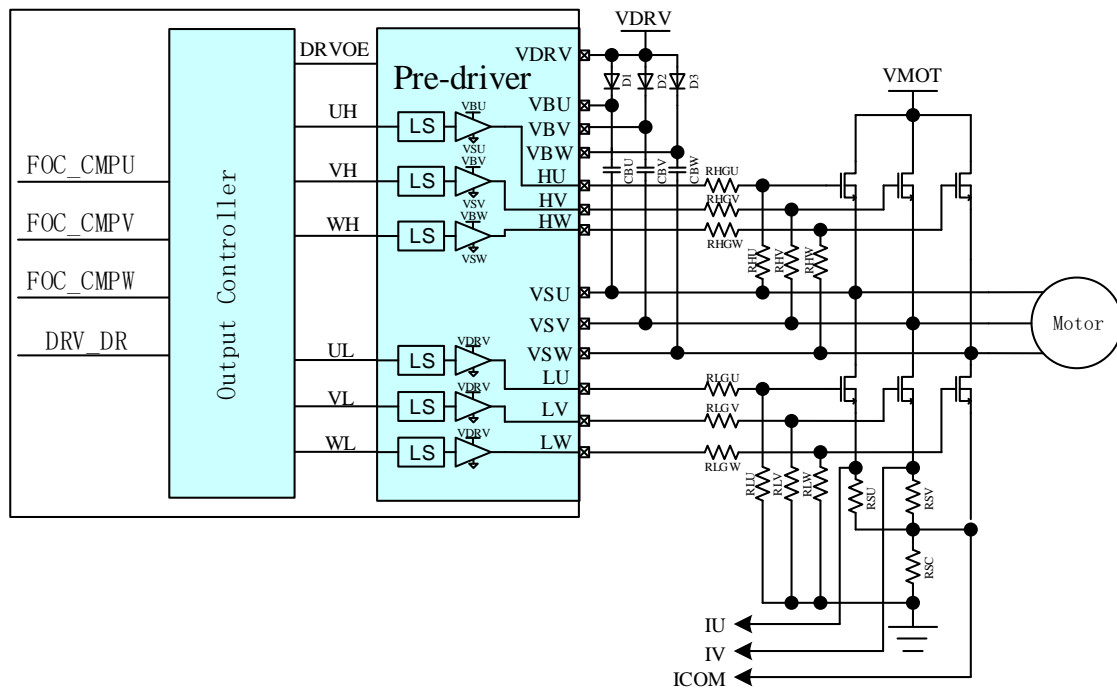


Figure 18-2 Block Diagram of FU6865Q/FU6864Q/FU6864L Driver Module

FOC\_CMPU/V/W is the three-way comparison value output by FOC module, and DRV\_DR is the comparison value set by the software. The above comparison value outputs four sets of level signals U/V/W/X to PWM output (FU6815L) or three sets of level signals U/V/W to pre-driver (FU6865Q/FU6864Q/FU6864L) after passing through the output control module. The U/V/W three-way output is applied to DC brushless motor control, and the U/V/W/X four-way output to step motor control.



### 18.1.2 Output Control Module

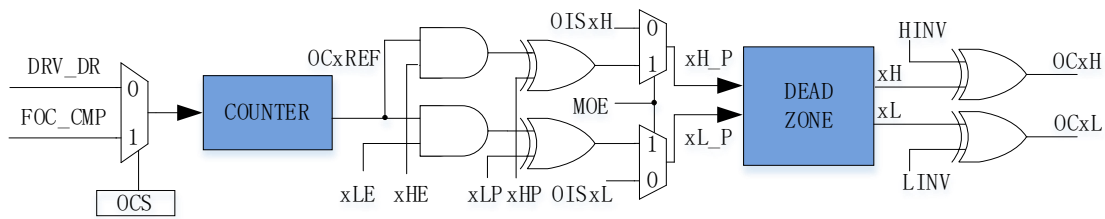


Figure 18-3 Block Diagram of Output Control Module

Before Driver module works, DRV\_CR[MESEL] is set to “1” to select FOC mode or to “0” to select square-wave control mode.

If DRV\_CR[OCS] = 0, comparison value of PWM comes from DRV\_DR. Otherwise, it comes from FOC\_CMP and U/V/W/X output signals (OCxREF) are generated. DRV\_CMR[xHE], DRV\_CMR[xLE], polarity control bits DRV\_CMR[xHP] and DRV\_CMR[xLP] are configured for logic processing of OCxREF signal. Enabling DRV\_OUT[MOE] outputs PWM waveform, otherwise, the idle level. xH\_P and xL\_P output signals are transferred to the deadtime module to generate xH and xL signals. The PI\_CR[HINV] and PI\_CR[LINV] bits are configured to output PWM drive signals required by the high and low levels.

#### 18.1.2.1 Count and Compare Module

DRV\_CR[OCS] is configured to select the comparison value of PWM from FOC\_CMPU/V/W of FOC module or DRV\_DR set by software. The comparison value is sent to the counter for comparison to obtain the 3-phase original PWM signal OCxREF, and DRV\_DR is used for motor pre-charging, braking and square-wave control. If DRV\_CNTR is smaller than the comparison value, OCxREF outputs high-level signal, and if DRV\_CNTR is larger than DRV\_DR, OCxREF outputs low-level signal.

When DRV\_CR[OCS] = 1, FOC\_CMPU/V/W is compared with the count value to generate the duty cycle OC1REF/OC2REF/OC3REF.

When DRV\_CR[OCS] = 0, DRV\_DR set by software is compared with the count value to generate OC1REF/OC2REF/OC3REF with the same duty cycle. Duty cycle =  $DRV\_DR/DRV\_ARR * 100\%$ .

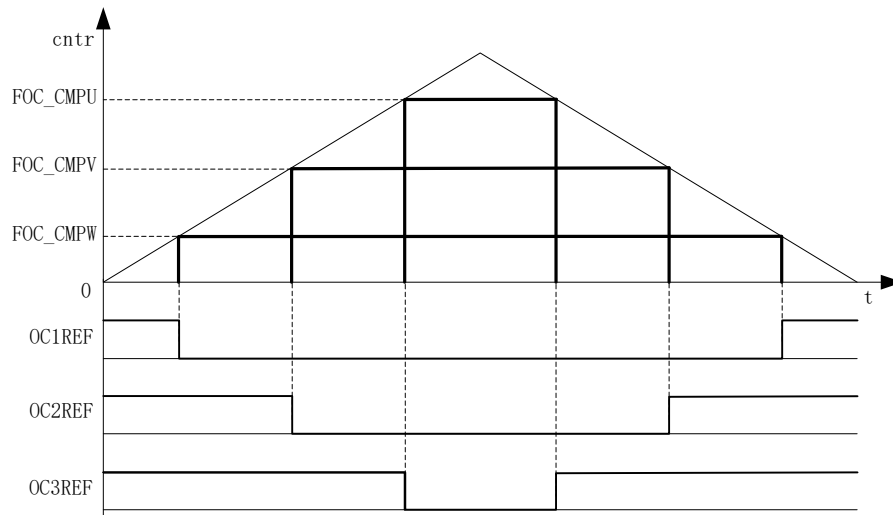


Figure 18-4 PMW Generation

### 18.1.2.2 Deadtime Module

$xH\_P$  and  $xL\_P$  signals are available for deadtime insertion. For complementary outputs, the deadtime insertion is enabled when  $DRV\_DTR$  is not "0". Each channel has an 8-bit deadtime generator, and three channels have the same deadtime, which is set by  $DRV\_DTR$ . When rising edge signals are detected, output high level of  $xH$  and  $xL$  is delayed for a period of time set in  $DRV\_DTR$ ; if the delayed time is greater than the output pulse width, the associated channel pulse width is not delayed.

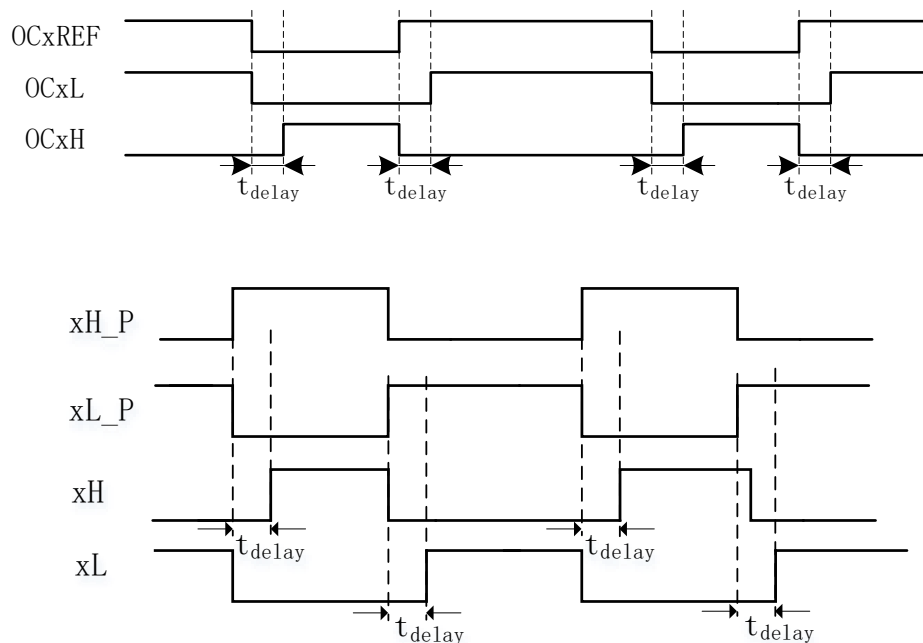


Figure 18-5 Complementary Outputs with Deadtime Insertion

### 18.1.2.3 Enable and Polarity of Output Signals

DRV\_CM[xHE] and [xLE] are configured by software to enable high and low sides of the bridge, and DRV\_CM[xHP] and [xLP] to select the polarity of output. For square-wave control, Timer1 automatically controls DRV\_CM to implement phase commutation. Configuring DRV\_CR[MESEL] = 0 enables the Square Wave Drive Mode. After Timer1 generates a write timing, the data stored in the corresponding TIM1\_DBRx are transferred to the DRV\_CM register.

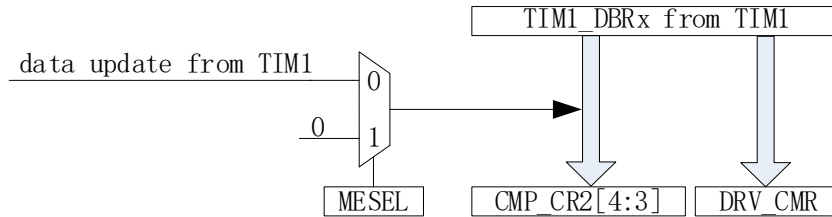


Figure 18-6 Timer1 Automatic Control of DRV\_CM and CMP\_CR2[4:3]

DRV\_DR, DRV\_ARR and DRV\_CM can be configured to implement pre-charging brake, etc. DRV\_DR and DRV\_ARR control the duty cycle and frequency of PWM. DRV\_OUT[MOE] decides the output mode as idle level or PWM.

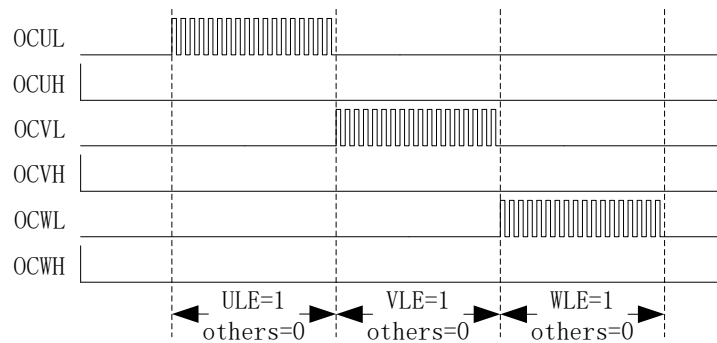


Figure 18-7 Pre-charge Waveform

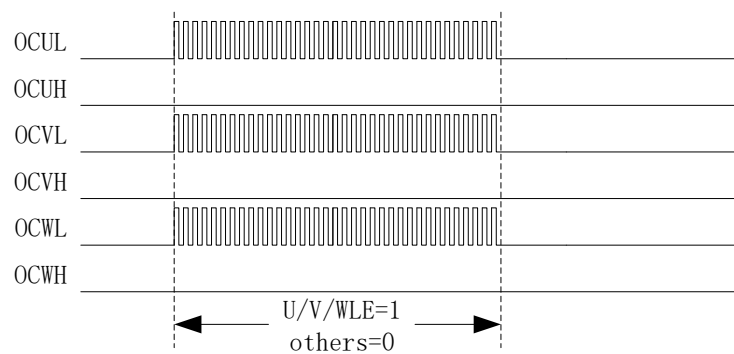


Figure 18-8 Brake Waveform

### 18.1.2.4 Interrupt

#### 18.1.2.4.1 Compare Match Interrupt

The generation conditions and time for compare match interrupt are configured by DRV\_SR[DCIM] and DRV\_COMR respectively. When the timer reaches the value set in DRV\_COMR and the conditions set by DRV\_SR[DCIM] are met, a compare match interrupt is generated and the interrupt flag DRV\_SR[DCIF] is set to “1” by hardware.

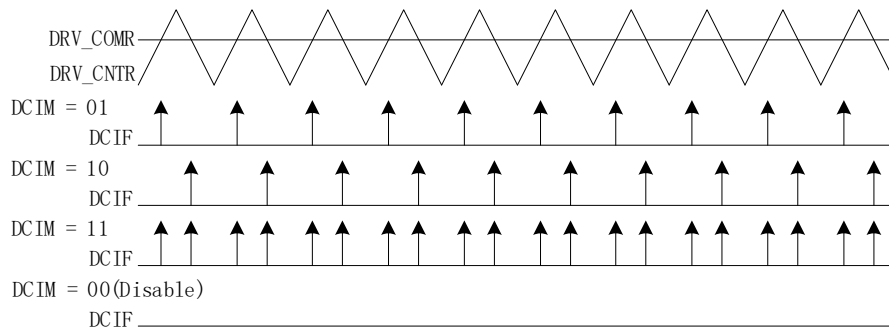


Figure 18-9 Driver Compare Match Interrupt

#### 18.1.2.4.2 FG Interrupt

FG interrupt is enabled when DRV\_SR[FGIE] is set to “1”. The motor generates an interrupt for every electrical cycle.

### 18.1.3 PWM Mode (FU6815L)

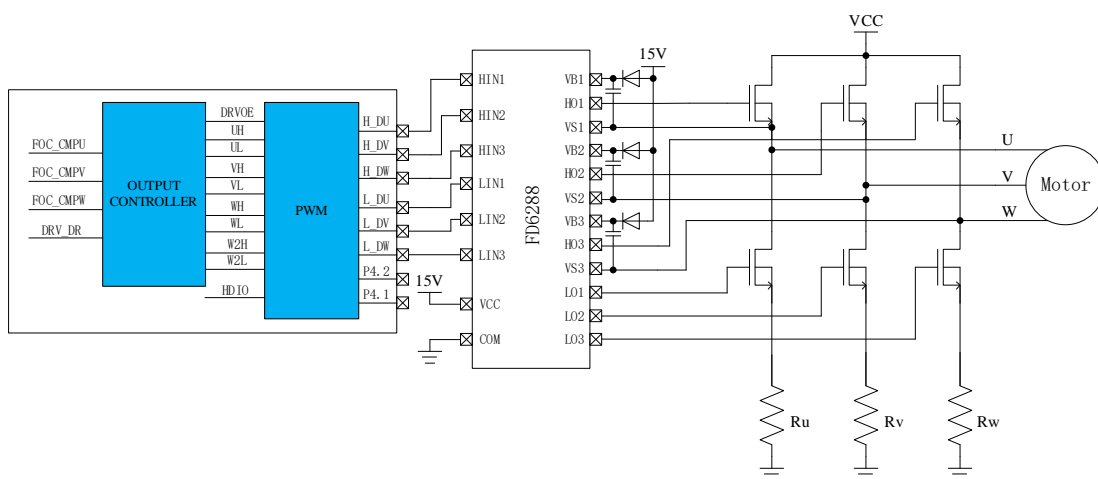


Figure 18-10 Block Diagram of PWM Mode

FU6815L adopts PWM output IC, as shown in Figure 18-10. Configuring DRV\_CR[DRVOE] enables PWM mode, where the PWM output is connected to HVIC that drives the MOS gate.



[2]	DRVMD	Count Mode 0: Triangular Wave Mode 1: Sawtooth Wave Mode (FOC disabled)
[1]	HINV	High Side Reverse Enable 0: Disable 1: Enable
[0]	LINV	Low Side Reverse Enable 0: Disable 1: Enable

### 18.2.2 DRV\_CR (0x4062)

Bit	7	6	5	4	3	2	1	0
Name	DRVEN	DDIR	FOCEN	DRPE	OCS	MESEL	RSV	DRVOE
Type	R/W	R/W	R/W	R/W	R/W	R/W	-	R/W
Reset	0	0	0	0	0	0	-	0

Bit	Name	Description
[7]	DRVEN	Counter Enable 0: Disable 1: Enable
[6]	DDIR	Output Direction (Forward/Reverse) Switch motor rotation directions; Valid in both square-wave drive and FOC drive modes. In sensorless FOC mode, setting this bit changes motor rotation. In sensed FOC mode, it is also required to modify the angle by the software. In square-wave control mode, parameters related to Timer1 shall be configured. 0: Forward 1: Reverse
[5]	FOCEN	FOC Module Enable 0: Disable 1: Enable
[4]	DRPE	DRV_DR Pre-load Enable When preload is enabled, the data written to DRV_DR is updated after a timer underflow event occurs. When preload is disabled, the data written to DRV_DR is updated immediately. 0: Disable 1: Enable
[3]	OCS	Comparison Source Selection 0: DRV_DR 1: FOC Module
[2]	MESEL	ME Operating Mode Selection 0: Square Wave Drive 1: FOC Drive
[1]	RSV	Reserved
[0]	DRVOE	Driver Enable 0: Disable 1: Enable

### 18.2.3 DRV\_SR (0x4061)

Bit	7	6	5	4	3	2	1	0
Name	SYSTIF	SYSTIE	FGIF	DCIF	FGIE	DCIP	DCIM	
Type	R/W0	R/W	R/W0	R/W0	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
-----	------	-------------

[7]	SYSTIF	Systick Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect
[6]	SYSTIE	Systick Interrupt Enable 0: Disable 1: Enable
[5]	FGIF	FG Interrupt Flag Read 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect
[4]	DCIF	Driver Match Interrupt Flag When the Driver count value is equal to DRV_COMR, the system decides whether to generate an interrupt according to DRV_SR[DCIM]. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect
[3]	FGIE	FG Interrupt Enable After the interrupt feature is enabled, an FG Interrupt is generated in each electric cycle under FOC/square-wave control mode. 0: Disable 1: Enable
[2]	DCIP	Number of PWM cycles to generate a Compare Match Interrupt 0: 1 PWM cycle 1: 2 PWM cycles
[1:0]	DCIM	Compare Match Interrupt Mode Selection When the Driver count value is equal to DRV_COMR, the system decides whether to generate an interrupt according to DRV_SR[DCIM]. 00: No interrupt is generated. 01: An interrupt is generated when the timer counts up. 10: An interrupt is generated when the timer counts down. 11: An interrupt is generated when the timer counts up/down.

#### 18.2.4 DRV\_OUT (0xF8)

Bit	7	6	5	4	3	2	1	0
Name	MOE	RSV	OISWL	OISWH	OISVL	OISVH	OISUL	OISUH
Type	R/W	-	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	-	0	0	0	0	0	0
Bit	Name	Description						
[7]	MOE	Main Output Enable This bit selects the sources for high and low sides of the bridge of 3-phase output signals. It can be set to “1” and “0” by software. When bus current protection occurs, it is automatically cleared to “0” to turn off the output (see section 29.1.1.1). 0: Disable, with output sourced from the idle levels set by DRV_OUT[OISUH]/DRV_OUT[OISVH]/DRV_OUT[OISWH] and DRV_OUT[OISUL]/DRV_OUT[OISVL]/DRV_OUT[OISWL]. 1: Enable, with output sourced from the comparison value of the timer.						
[6]	RSV	Reserved						

[5]	OISWL	Output idle level of WL/XL See descriptions on OISUH register. Note: DRV_OUT[OISWL] bit is configured as WL/XL output in IDLE state.
[4]	OISWH	Output idle level of WH/XH See descriptions on OISUH register. Note: DRV_OUT[OISWH] bit is configured as WH/XH output in IDLE state.
[3]	OISVL	Output idle level of VL See descriptions on OISUH register
[2]	OISVH	Output idle level of VH See descriptions on OISUH register.
[1]	OISUL	Output idle level of UL See descriptions on OISUH register.
[0]	OISUH	Output idle level of UH This bit sets the UH output in IDLE state. When DRV_OUT[MOE] = 0, it outputs idle level to disable MOS. 0: Low 1: High

### 18.2.5 DRV\_CMRR (0x405C, 0x405D)

DRV_CMRR(0x405C)								
Bit	15	14	13	12	11	10	9	8
Name	XHP	XHL	XHE	XLE	WHP	WLP	VHP	VLP
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
DRV_CMRL(0x405D)								
Bit	7	6	5	4	3	2	1	0
Name	UHP	ULP	WHE	WLE	VHE	VLE	UHE	ULE
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15]	XHP	High-side Polarity Control of X-phase 0: Active High 1: Active Low						
[14]	XLP	Low-side Polarity Control of X-phase 0: Active High 1: Active Low						
[13]	XHE	High-side Output Enable of X-phase 0: Disable 1: Enable						
[12]	XLE	Low-side Output Enable of X-phase 0: Disable 1: Enable						
[11]	WHP	High-side Polarity Control of W-phase 0: Active High 1: Active Low						
[10]	WLP	Low-side Polarity Control of W-phase 0: Active High 1: Active Low						
[9]	VHP	High-side Polarity Control of V-phase 0: Active High 1: Active Low						
[8]	VLP	Low-side Polarity Control of V-phase 0: Active High 1: Active Low						



[7]	UHP	High-side Polarity Control of U-phase 0: Active High 1: Active Low
[6]	ULP	Low-side Polarity Control of U-phase 0: Active High 1: Active Low
[5]	WHE	High-side Output Enable of W-phase 0: Disable 1: Enable
[4]	WLE	Low-side Output Enable of W-phase 0: Disable 1: Enable
[3]	VHE	High-side Output Enable of V-phase 0: Disable 1: Enable
[2]	VLE	Low-side Output Enable of V-phase 0: Disable 1: Enable
[1]	UHE	High-side Output Enable of U-phase 0: Disable 1: Enable
[0]	ULE	Low-side Output Enable of U-phase 0: Disable 1: Enable

Notes:

- When DRV\_CM[R/W/V/ULE] and DRV\_CM[R/W/V/UHE] are set to “1”, high-side and low-side outputs of W/V/U-phases are complementary to generate PWM signals with deadtime insertion.
- For square-wave control, Timer1 automatically controls DRV\_CM[R/W/V/ULE] register.

### 18.2.6 DRV\_ARR (0x405E, 0x405F)

DRV_ARRH(0x405E)								
Bit	15	14	13	12	11	10	9	8
Name	RSV		DRV_ARR[13:8]					
Type	-	-	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	-	0	0	0	0	0	0
DRV_ARRL(0x405F)								
Bit	7	6	5	4	3	2	1	0
Name	DRV_ARR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:14]	RSV	Reserved						
[13:0]	DRV_ARR	Timer reload value, which determines PWM frequency (center-aligned) Driver timer up-counts from 0 to DRV_ARR/2 - 1 and an overflow event occurs. Then it down-counts to 0. Calculation formula: $f_{carrier} = 48\text{MHz}/\text{DRV\_ARR}$ DRV_ARR value is calculated using 48MHz clock rate, which falls within the range [0, 16383]. Note: The LSB is always 0, and a write of “1” is meaningless.						

**18.2.7 DRV\_COMR (0x405A, 0x405B)**

DRV_COMRH(0x405A)								
Bit	15	14	13	12	11	10	9	8
Name	RSV				DRV_COMR[11:8]			
Type	-	-	-	-	R/W	R/W	R/W	R/W
Reset	-	-	-	-	0	0	0	0
DRV_COMRL(0x405B)								
Bit	7	6	5	4	3	2	1	0
Name	DRV_COMR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:12]	RSV	Reserved						
[11:0]	DRV_COMR	Timer Compare Match Value The compare match interrupt is generated when the count value is equal to DRV_COMR and the conditions set in DRV_SR[DCIM] are met. The clock rate for the calculation is 12MHz. Duty cycle at the match point = $DRV\_COMR * 4 / DRV\_ARR * 100\%$ DRV_COMR value is calculated using 12MHz clock rate, which falls within the range [0, 4095].						

**18.2.8 DRV\_DR (0x4058, 0x4059)**

DRV_DRH(0x4058)								
Bit	15	14	13	12	11	10	9	8
Name	RSV		DRV_DR[13:8]					
Type	-	-	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	-	0	0	0	0	0	0
DRV_DRL(0x4059)								
Bit	7	6	5	4	3	2	1	0
Name	DRV_DR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:14]	RSV	Reserved						
[13:0]	DRV_DR	PWM Duty Cycle Setting in Software Duty cycle = $DRV\_DR / DRV\_ARR * 100\%$ DRV_DR value is calculated using 48MHz clock rate, which falls within the range [0, 16383].  Note: When this register is used as a comparison source, PWM is referenced to high side of the bridge and a deadtime is inserted in the complementary output of the low side of bridge.						

**18.2.9 DRV\_DTR (0x4060)**

Bit	7	6	5	4	3	2	1	0
Name	DRV_DTR							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[7:0]	DRV_DTR	Deadtime Setting $Deadtime = (DRV\_DTR + 1) * T$ Example: If DRV_DTR is configured to "11", the deadtime = $12 * 41.67ns = 500ns$ .  Note: If DRV_DTR is configured to "0", deadtime insertion is disabled.

### 18.2.10 DRV\_\_CNTR (0x4066, 0x4067)

DRV__CNTRH(0x4066)								
Bit	15	14	13	12	11	10	9	8
Name	RSV				DRV__CNTR[11:8]			
Type	-	-	-	-	R/W	R/W	R/W	R/W
Reset	-	-	-	-	0	0	0	0
DRV__CNTRL(0x4067)								
Bit	7	6	5	4	3	2	1	0
Name	DRV__CNTR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:12]	RSV	Reserved						
[11:0]	DRV__CNTR	Count Value of Timer The clock rate for the calculation is 12MHz, and Driver duty cycle = $DRV\_CNTR * 4 / DRV\_ARR * 100\%$ Range [0, 4095]  Note: The DRV__CNTR register is writable only when $DRV\_CR[DRVEN] = 1$ .						

## 19 Clock

### 19.1 Introduction

The clock consists of three modules: Internal Fast Clock, Internal Slow Clock and External Slow Clock. The system clock operates as an Internal Fast Clock. Internal Slow Clock is used as WDT for configuring overflow time of the watchdog. External Slow Clock is used for RTC counts.

### 19.2 Clock Operations

#### 19.2.1 External Slow Clock (FU6815L/FU6865Q)

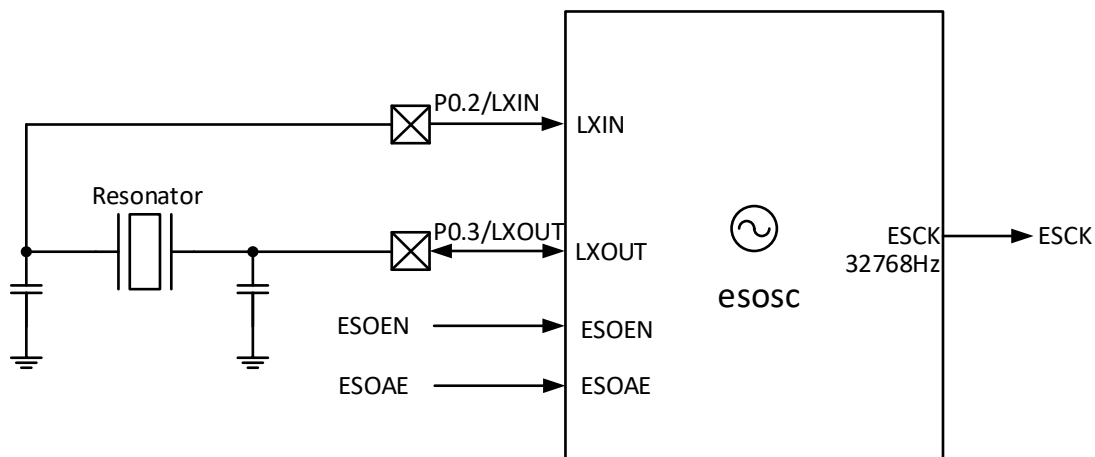


Figure 19-1 Input/Output of External Slow Clock on esosc Pin

The I/O pins of the External Slow Clock are shown in Figure 19-1. External Slow Clock is used to produce a clock signal with a rate of 32768Hz. It is enabled when  $RTC\_STA[ESOEN] = 1$  and  $RTC\_STA[ESOAE] = 1$ .

### 19.3 Clock Calibration

#### 19.3.1 Introduction

Clock calibration is a feature that uses internal slow clock to calibrate the internal fast clock. Working principles: A 13-bit timer is used to count the length of 8 slow clock cycles with the fast clock as the clock source.

Calibration operations: Set  $CAL\_CR0[CAL\_STA] = 1$  in software to start the calibration. Read  $CAL\_CR0[CAL\_BUSY]$  flag bit to check if the calibration process is completed. When the calibration is completed ( $CAL\_CR0[CAL\_BUSY] = 0$ ), the readout of  $CAL\_CR0[CAL\_ARR]$  is the value of the length of counting 8 slow clock cycles.

### 19.3.2 Clock Calibration Registers

#### 19.3.2.1 CAL\_CR0 (0x4044) CAL\_CR1 (0x4045)

CAL_CR0(0x4044)								
Bit	15	14	13	12	11	10	9	8
Name	CAL_STA/ CAL_BUSY	RSV		CAL_ARR[12:8]				
Type	R/W1	-	-	R/W	R/W	R/W	R/W	R/W
Reset	1	-	-	0	0	0	0	0
CAL_CR1(0x4045)								
Bit	7	6	5	4	3	2	1	0
Name	CAL_ARR[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15]	CAL_STA/ CAL_BUSY	Clock Calibration Enable Read: 0: Calibration is completed. 1: Calibration is in progress. Write: 0: No effect 1: Clock Calibration starts.						
[14:13]	RSV	Reserved						
[12:0]	CAL_ARR	Calibration Counts The count values of the fast clock to continuously count eight slow clock cycles  Note: When this value is 0, it indicates that no corresponding slow clock input exists, and when this value is 0x1FFF, it indicates that the count overflows (slow clock is too slow or fast clock is too fast).						

## 20 WDT

The watchdog timer (WDT) is a timer that works on the internal slow clock to monitor the master program operation and prevent the MCU running out. Watchdog works as follows: After watchdog operates, WDT starts counting. When WDT overflows, watchdog sends a signal to reset the MCU and the program restarts running from address 0. During the operation of master program, WDT has to be initialized at regular intervals to prevent WDT overflowing.

After being enabled, WDT starts counting from 0. When it reaches 0xFFFC, watchdog outputs a signal that is 4 internal slow clock cycles wide to reset MCU, and the program starts running from address 0. WDT has to be initialized at regular intervals during operation, and WDT rolls over to WDT\_ARR and restart counting.

### 20.1 WDT Notes

- When MCU enters standby or sleep mode, WDT stops counting, but the count values are retained.
- WDT is automatically disabled during emulation.
- RST\_SR[RSTWDT] is set to “1” when MCU is reset by WDT timer overflow.

### 20.2 WDT Operations

1. Set CCFG1[WDT\_EN] = 1 to start WDT, which then starts counting from 0;
2. Set WDT\_ARR (this operation can also be performed before starting WDT);
3. Set WDT\_CR[WDTRF] = 1 in the running of program, and WDT rolls over to WDT\_ARR setting.

## 20.3 WDT Registers

### 20.3.1 WDT\_CR (0x4026)

Bit	7	6	5	4	3	2	1	0
Name	RSV							WDTRF
Type	-	-	-	-	-	-	-	R/W
Reset	-	-	-	-	-	-	-	0
Bit	Name	Description						
[7:1]	RSV	Reserved						
[0]	WDTRF	WDT Initialization 0: No effect 1: WDT rolls over to WDT_ARR setting and restarts counting.						

### 20.3.2 WDT\_ARR (0x4027)

Bit	7	6	5	4	3	2	1	0
Name	WDT_ARR							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	WDT_ARR	WDT Reload Timer This bit sets 8 high-order bits of the initialized value of WDT.						

### 20.3.3 CCFG1 (0x401E)

Bit	7	6	5	4	3	2	1	0
Name	RSV	LVWIE	WDT_EN	RSV				
Type	-	R/W	R/W	-	-	-	-	-
Reset	-	0	0	-	-	-	-	-
Bit	Name	Description						
[7]	RSV	Reserved						
[6]	LVWIE	LVW Detection Interrupt Enable 0: Disable 1: Enable						
[5]	WDT_EN	WDT Enable 0: Disable 1: Enable						
[4:0]	RSV	Reserved						

## 21 RTC

### 21.1 RTC Functional Block Diagram

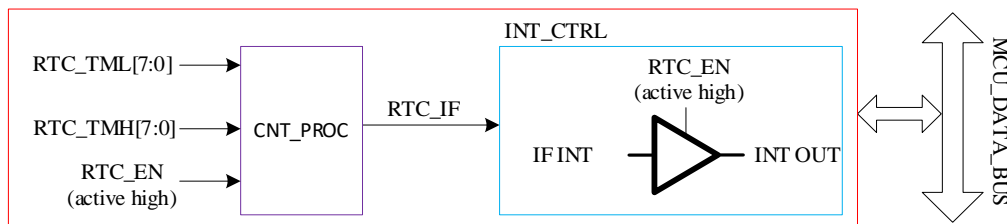


Figure 21-1 RTC Functional Block Diagram

### 21.2 RTC Operations

A write to RTC\_TM sets RTC reload value. RTC is enabled when RTC\_STA[RTC\_EN] is set to “1”.

### 21.3 RTC Registers

#### 21.3.1 RTC\_TM (0x402C, 0x402D)

RTC_TMH(0x402C)								
Bit	15	14	13	12	11	10	9	8
Name	RTC_TM[15:8]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	1	1	1	1	1	1	1	1
RTC_TML(0x402D)								
Bit	7	6	5	4	3	2	1	0
Name	RTC_TM[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	1	1	1	1	1	1	1	1
Bit	Name	Description						
[15:0]	RTC_TM	RTC Count Register Read: Instantaneous value of the timer Write: RTC timer up-counts at a rate of 32768Hz from 0 to the written value and becomes overflowed. Meanwhile, an interrupt request is generated, causing the timer to be cleared and restart counting.						

#### 21.3.2 RTC\_STA (0x402E)

Bit	7	6	5	4	3	2	1	0
Name	RTC_EN	RTC_IF	ISOSCSEL	ISOSCEN	ESOAЕ	ESOEN	ESCLKSEL	RSV
Type	R/W	R/W0	R/W	R/W	R/W	R/W	R/W	-
Reset	0	0	0	0	0	0	0	-
Bit	Name	Description						
[7]	RTC_EN	RTC Enable 0: Disable 1: Enable						
[6]	RTC_IF	RTC Interrupt Flag This bit is set to “1” when the timer value matches RTC_TM setting. Read: 0: No Interrupt Pending						



		1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect
[5]	ISOSCSEL	Slow Clock Source Selection 0: Internal Slow Clock 1: External Slow Clock
[4]	ISOSCEN	Internal Slow Clock Enable 0: Disable 1: Enable
3	ESOAЕ	External Slow Clock Analog Form 0: Digital form. 1: Analog form. When an External Slow Clock is selected, the analog form must be configured.
2	ESOEN	External Slow Clock Enable 0: Disable 1: Enable
[1]	ESCLKSEL	External Slow Clock Source Selection 0: Analog Input 1:P1.1 Input
[0]	RSV	Reserved

## 22 IO

### 22.1 IO Introduction

FU6815L has up to 38 GPIO pins, including P0.0~P0.7, P1.0~P1.7, P2.0~P2.7, P3.0~P3.7, P4.1~P4.2, P4.4, P4.6~P4.7 and P5.1.

FU6865Q has up to 36 GPIO pins, including P0.0~P0.7, P1.0~P1.7, P2.0~P2.7, P3.0~P3.7, P4.4, P4.6~P4.7 and P5.1.

FU6864Q has up to 22 GPIO pins, including P0.0~P0.1, P0.3, P1.1~P1.7, P2.1~P2.2, P2.4, P2.6~P2.7, P3.0~P3.1, P3.3~P3.5, P4.5 and P4.7.

FU6864L has up to 24 GPIOs, including P0.0~P0.1, P0.3, P1.1~P1.7, P2.1~P2.7, P3.0~P3.5 and P4.7.

### 22.2 IO Operations

Each GPIO port pin has relevant registers to meet different application requirements. For example, P0.0 is mapped to register P0, and P1.0 to register P1. P0\_OE and P1\_OE registers are configured for digital input and output.

Notes:

- The chip cannot perform external reset in IO port mode.
- The signal frequency in IO port mode must be less than 100kHz.
- P4.7 is a fixed port for input, and works in FICEK mode by default. If you want it to work in IO port mode, deselect FICEK\_MOD in the configuration tool.
- The enable bits of pull-up resistors and pull-down resistors are configured to “1”. See 22.3.10 P0\_PU (0x4053) ~ 22.3.15 P5\_PU (0x4048) for port pins and registers.
- See 5.3 GPIO Electrical Characteristics for the values of pull-up resistors and pull-down resistors.
- The relevant bits of P1\_AN, P2\_AN and P3\_AN registers are configured to “1” to activate analog signal mode. See 22.3.7 P1\_AN (0x4050) ~ 22.3.9 P3\_AN (0x4052) for port pins and registers. After the port pins are configured to analog mode, all their digital features are disabled and the port state is 0 by reading relevant bits in P1, P2 and P3 registers.
- Pull-up resistors of P1.6~P1.7, P2.0~P2.7, P3.0~P3.5 are automatically disabled when the port pins are configured as analog mode.

## 22.3 IO Registers

### 22.3.1 P0\_OE (0xFC)

Bit	7	6	5	4	3	2	1	0
Name	P0_OE							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	P0_OE	P0.0 ~P0.7 Digital I/O Selection 0: Input 1: Output						

### 22.3.2 P1\_OE (0xFD)

Bit	7	6	5	4	3	2	1	0
Name	P1_OE							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	P1_OE	P1.0 ~P1.7 Digital I/O Selection 0: Input 1: Output						

### 22.3.3 P2\_OE (0xFE)

Bit	7	6	5	4	3	2	1	0
Name	P2_OE							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	P2_OE	P2.0 ~P2.7 Digital I/O Selection 0: Input 1: Output						

### 22.3.4 P3\_OE (0xFF)

Bit	7	6	5	4	3	2	1	0
Name	P3_OE							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	P3_OE	P3.0 ~P3.7 Digital I/O Selection 0: Input 1: Output						

### 22.3.5 P4\_OE (0xE9)

Bit	7	6	5	4	3	2	1	0
Name	RSV	P46_OE	P45_OE	P44_OE	RSV	P42_OE	P41_OE	P40_OE
Type	-	R/W	R/W	R/W	-	R/W	R/W	R/W
Reset	-	0	0	0	-	0	0	0

Bit	Name	Description
[7]	RSV	Reserved
[6]	P46_OE	P4.6 Digital I/O Selection 0: Input 1: Output
[5]	P45_OE	P4.5 Digital I/O Selection 0: Input 1: Output
[4]	P44_OE	P4.4 Digital I/O Selection 0: Input 1: Output
[3]	RSV	Reserved
[2]	P42_OE	P4.2 Digital I/O Selection 0: Input 1: Output
[1]	P41_OE	P4.1 Digital I/O Selection 0: Input 1: Output
[0]	P40_OE	P4.0 Digital I/O Selection 0: Input 1: Output

### 22.3.6 P5\_OE (0xFB)

Bit	7	6	5	4	3	2	1	0
Name	RSV						P51_OE	RSV
Type	-	-	-	-	-	-	R/W	-
Reset	-	-	-	-	-	-	0	-

Bit	Name	Description
[7:2]	RSV	Reserved
[1]	P51_OE	P5.1 Digital I/O Selection 0: Input 1: Output
[0]	RSV	Reserved

### 22.3.7 P1\_AN (0x4050)

Bit	7	6	5	4	3	2	1	0
Name	P1_AN				HBMOD	HDIO	ODE1	ODE0
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[7:4]	P1_AN	P1.4 ~P1.7 Analog Mode Enable 0: Disable 1: Enable

[3]	HBMOD	P1.3 mode configuration, which determines the functional mode of P1.3 in combination with P1_OE[3], as shown in Table 22-1.															
		Table 22-1 P1.3 Mode Setting															
		<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 15%;">HBMOD</th> <th style="width: 15%;">P1_OE[3]</th> <th style="width: 70%;">P1.3 Pin Mode</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">0</td> <td style="text-align: center;">0</td> <td>Digital Input</td> </tr> <tr> <td style="text-align: center;">0</td> <td style="text-align: center;">1</td> <td>Digital Output</td> </tr> <tr> <td style="text-align: center;">1</td> <td style="text-align: center;">0</td> <td>Analog Mode</td> </tr> <tr> <td style="text-align: center;">1</td> <td style="text-align: center;">1</td> <td>Digital enhanced drive output mode. The maximum output current of high level output can be up to 20mA for Hall bias power supply. The drive mode of low level output is the same as that of the digital output mode.</td> </tr> </tbody> </table>	HBMOD	P1_OE[3]	P1.3 Pin Mode	0	0	Digital Input	0	1	Digital Output	1	0	Analog Mode	1	1	Digital enhanced drive output mode. The maximum output current of high level output can be up to 20mA for Hall bias power supply. The drive mode of low level output is the same as that of the digital output mode.
		HBMOD	P1_OE[3]	P1.3 Pin Mode													
		0	0	Digital Input													
0	1	Digital Output															
1	0	Analog Mode															
1	1	Digital enhanced drive output mode. The maximum output current of high level output can be up to 20mA for Hall bias power supply. The drive mode of low level output is the same as that of the digital output mode.															
[2]	HDIO	IO Driver Capability for PWM Output. It is valid for L_DU, L_DV, L_DW, H_DU, H_DV and H_DW of FU6815 only. 0: Normal drive capability 1: High drive capability															
[1]	ODE1	P0.1 Collector Open-Drain Output Enable 0: Disable 1: Enable															
[0]	ODE0	P0.0 Collector Open-Drain Output Enable 0: Disable 1: Enable															

### 22.3.8 P2\_AN (0x4051)

Bit	7	6	5	4	3	2	1	0
Name	P2_AN							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	P2_AN	P2.0 ~P2.7 Analog Mode Enable 0: Disable 1: Enable						

### 22.3.9 P3\_AN (0x4052)

Bit	7	6	5	4	3	2	1	0
Name	P11_PL	P01_PL	P3_AN					
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	P11_PL	P1.1 Pull-down Resistor Enable 0: Disable 1: Enable Note: The pull-up resistor and pull-down resistor of P1.1 pin cannot be enabled at the same time.						
[6]	P01_PL	P0.1 Pull-down Resistor Enable 0: Disable 1: Enable Note: The pull-up resistor and pull-down resistor of P0.1 pin cannot be enabled at the same time.						
[5:0]	P3_AN	P3.0 ~P3.5 Analog Mode Enable 0: Disable 1: Enable						

**22.3.10 P0\_PU (0x4053)**

Bit	7	6	5	4	3	2	1	0
Name	P0_PU							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	P0_PU	P0.0 ~P0.7 Pull-up Resistor Enable 0: Disable 1: Enable						

**22.3.11 P1\_PU (0x4054)**

Bit	7	6	5	4	3	2	1	0
Name	P1_PU							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	P1_PU	P1.0 ~P1.7 Pull-up Resistor Enable 0: Disable 1: Enable						

**22.3.12 P2\_PU (0x4055)**

Bit	7	6	5	4	3	2	1	0
Name	P2_PU							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	P2_PU	P2.0 ~P2.7 Pull-up Resistor Enable 0: Disable 1: Enable						

**22.3.13 P3\_PU (0x4056)**

Bit	7	6	5	4	3	2	1	0
Name	P3_PU							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	P3_PU	P3.0 ~P3.7 Pull-up Resistor Enable 0: Disable 1: Enable						

**22.3.14 P4\_PU (0x4057)**

Bit	7	6	5	4	3	2	1	0
Name	P47_PU	P46_PU	P45_PU	P44_PU	RSV	P42_PU	P41_PU	P40_PU
Type	R/W	R/W	R/W	R/W	-	R/W	R/W	R/W
Reset	0	0	0	0	-	0	0	0

Bit	Name	Description
[7]	P47_PU	P4.7 Pull-up Resistor Enable 0: Disable 1: Enable
[6]	P46_PU	P4.6 Pull-up Resistor Enable 0: Disable 1: Enable
[5]	P45_PU	P4.5 Pull-up Resistor Enable 0: Disable 1: Enable
[4]	P44_PU	P4.4 Pull-up Resistor Enable 0: Disable 1: Enable
[3]	RSV	Reserved
[2]	P42_PU	P4.2 Pull-up Resistor Enable 0: Disable 1: Enable
[1]	P41_PU	P4.1 Pull-up Resistor Enable 0: Disable 1: Enable
[0]	P40_PU	P4.0 Pull-up Resistor Enable 0: Disable 1: Enable

### 22.3.15 P5\_PU (0x4048)

Bit	7	6	5	4	3	2	1	0
Name		RSV		P47_PL	RSV	P51_PU	P45_AN	P46_AN
Type	-	-	-	R/W	-	R/W	R/W	R/W
Reset	-	-	-	0	-	0	0	0

Bit	Name	Description
[7:5]	RSV	Reserved
[4]	P47_PL	P4.7 Pull-down Resistor Enable 0: Disable 1: Enable
[3]	RSV	Reserved
[2]	P51_PU	P5.1 Pull-up Resistor Enable 0: Disable 1: Enable
[1]	P45_AN	P4.5 Analog Mode Enable 0: Disable 1: Enable
[0]	P46_AN	P4.6 Analog Mode Enable 0: Disable 1: Enable

### 22.3.16 PH\_SEL (0x404C)

Bit	7	6	5	4	3	2	1	0
Name	SPITMOD	UART1EN	UART2EN	T4SEL	T3SEL	T2SEL	T2SSEL	XOE
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[7]	SPITMOD	MISO port status after SPI slave device completes transmission 0: Output State 1: High-impedance State

[6]	UART1EN	Port multiplexed as RXD, TXD and UART1 enabled 0: Disable 1: P0.5 and P0.6 pins multiplexed as RXD and TXD pins and UART1 enabled
[5]	UART2EN	Port multiplexed as RXD2, TXD2 and UART2 enabled 0: Disable 1: P3.7, P1.2 and P0.0 pins multiplexed as TXD2 pin; P3.6, P4.7 and P0.1 pins multiplexed as RXD2 pin; and UART2 enabled.
[4]	T4SEL	Port pins multiplexed as Timer4 or Timer4S 0: Disable 1: P0.1 or P0.0 or P1.2 (by configuring PH_SEL1[T4CT1:T4CT0]) multiplexed as Timer4 I/O pins.
[3]	T3SEL	Port pins multiplexed as Timer3 or Timer3S 0: Disable 1: P1.1 or P0.1 or P4.7 (by configuring PH_SEL1[T4CT1:T4CT0]) multiplexed as Timer3 I/O pins (P4.7 for input only)
[2]	T2SEL	Port pins multiplexed as Timer2 0: Disable 1: P1.0 pin multiplexed as Timer2 I/O pins
[1]	T2SSEL	Port pins multiplexed as Time2S 0: Disable 1: P0.7 pin multiplexed as Timer2 I/O pins
[0]	XOE	X-phase Output Enable 0: Disable 1: Output enabled, with P4.1 configured as the X-phase low-side PWM output pin and P4.2 configured as the X-phase high-side PWM output pin

### 22.3.17 PH\_SEL1 (0x404D)

Bit	7	6	5	4	3	2	1	0
Name	UART2CH1	UART2CH0	CMPXO_P01	SPICT	T4CT1	T4CT0	T3CT1	T3CT0
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[7:6]	UART2CH	UART2 Functional Switching 00: P3.6 serving as RXD, and P3.7 pin as TXD (P3.6 is an I/O pin of 1-wire mode) 01: P4.7 serving as RXD, and P1.2 serving as TXD (P1.2 is an I/O pin of 1-wire mode) 1X: P0.1 serving as RXD, and P0.0 pin as TXD (P0.1 is an I/O pin in 1-wire mode)
[5]	CMPXO_P01	Comparator Functional Switching 0: No function switching, with P07 pin serving as output 1: Function switching, with P01 pin serving as output
[4]	SPICT	Debug Function Switching of SPI Working in 1-wire mode 0: No function switching, with P0.5 pin serving as SPI debug output 1: Function switching, with P0.0 pin serving as SPI debug output
[3:2]	T4CT	Timer4 Functional Switching 00: Timer4 I/O pin switched to P0.1 X1: Timer4 I/O pin switched to P0.0 10: Timer4 I/O pin switched to P1.2
[1:0]	T3CT	Timer3 Functional Switching 00: Timer3 I/O pin switched to P1.1 X1: Timer3 I/O pin switched to P0.1 10: Timer3 input pin switched to P4.7



**22.3.18 P0 (0x80)**

Port output register P0/1/2/3/4/5 supports read and write access. RMW commands are used to access the register value (see Table 22-2 for RMW commands), and other commands are used to access PORT pin.

Bit	7	6	5	4	3	2	1	0
Name	GP07	GP06	GP05	GP04	GP03	GP02	GP01	GP00
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	GP07	GP07 pin						
[6]	GP06	GP06 pin						
[5]	GP05	GP05 pin						
[4]	GP04	GP04 pin						
[3]	GP03	GP03 pin						
[2]	GP02	GP02 pin						
[1]	GP01	GP01 pin						
[0]	GP00	GP00 pin						

**22.3.19 P1 (0x90)**

.	7	6	5	4	3	2	1	0
Name	GP17	GP16	GP15	GP14	GP13	GP12	GP11	GP10
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	GP17	GP17 pin						
[6]	GP16	GP16 pin						
[5]	GP15	GP15 pin						
[4]	GP14	GP14 pin						
[3]	GP13	GP13 pin						
[2]	GP12	GP12 pin						
[1]	GP11	GP11 pin						
[0]	GP10	GP10 pin						

**22.3.20 P2 (0xA0)**

Bit	7	6	5	4	3	2	1	0
Name	GP27	GP26	GP25	GP24	GP23	GP22	GP21	GP20
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	GP27	GP27 pin						
[6]	GP26	GP26 pin						
[5]	GP25	GP25 pin						
[4]	GP24	GP24 pin						
[3]	GP23	GP23 pin						
[2]	GP22	GP22 pin						
[1]	GP21	GP21 pin						
[0]	GP20	GP20 pin						

**22.3.21 P3 (0xB0)**

Bit	7	6	5	4	3	2	1	0
Name	GP37	GP36	GP35	GP34	GP33	GP32	GP31	GP30
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	GP37	GP37 pin						
[6]	GP36	GP36 pin						
[5]	GP35	GP35 pin						
[4]	GP34	GP34 pin						
[3]	GP33	GP33 pin						
[2]	GP32	GP32 pin						
[1]	GP31	GP31 pin						
[0]	GP30	GP30 pin						

**22.3.22 P4 (0xB8)**

Bit	7	6	5	4	3	2	1	0
Name	GP47	GP46	GP45	GP44	GP43	GP42	GP41	GP40
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	GP47	GP47 pin						
[6]	GP46	GP46 pin						
[5]	GP45	GP45 pin						
[4]	GP44	GP44 pin						
[3]	GP43	GP43 pin						
[2]	GP42	GP42 pin						
[1]	GP41	GP41 pin						
[0]	GP40	GP40 pin						

**22.3.23 P5 (0xC0)**

Bit	7	6	5	4	3	2	1	0
Name	RSV				GP53	GP52	GP51	GP50
Type	-	-	-	-	R/W	R/W	R/W	R/W
Reset	-	-	-	-	0	0	0	0
Bit	Name	Description						
[7:4]	RSV	Reserved						
[3]	GP53	GP53 pin						
[2]	GP52	GP52 pin						
[1]	GP51	GP51 pin						
[0]	GP50	GP50 pin						

Table 22-2 RMW Commands

Command	Description
ANL	Bitwise logical AND operation
ORL	Bitwise logical OR operation
XRL	Bitwise logical XOR operation
JBC	Jump if the bit is set to "1" and then cleared to "0"
CPL	Bitwise logical converse operation
INC, DEC	+1, -1 logical operation
DJNZ	Jump if the bit is not "0"
MOV Px, y, C	Assign carry bit C to Px, y
CLR Px, y	Px, y is cleared to "0"
SETB Px, y	Px, y is set to "1"

## 23 ADC

### 23.1 ADC Introduction

The ADC module is a 12-bit successive approximation register ADC with 14 channels inside. The sampling mode supports sequential sampling (that is, from ADC Channel 0 to ADC channel 13 in sequence) and trigger sampling (including FOC triggered sampling mode and TIMER1 triggered sampling mode). The results of sequential sampling are stored in `ADCx_DR` ( $x = 0 \sim 13$ ) in a right-aligned or left-second-high-aligned format. The result of triggered sampling is sent to FOC module or TIMER1 module instead of `ADCx_DR` for motor control. The relevant registers of the FOC module or TIMER1 module are always left-second-high-aligned to store the triggered sample results. Triggered sampling is done automatically by hardware, and sequential sampling is controlled by software. The priority of triggered sampling is higher than that of sequential sampling. If both triggered sampling and sequential sampling are applied at the same time, the triggered sampling is performed first, and ADC automatically stores sequential sampling mode upon completion of triggered sampling.

The clock source of ADC is at a rate of 12MHz and the sampling time is set by `DAC_CR[5:2]` and `ADC_SCYC`. See ADC Electrical Characteristics for sample time and conversion time.

### 23.2 ADC Block Diagram

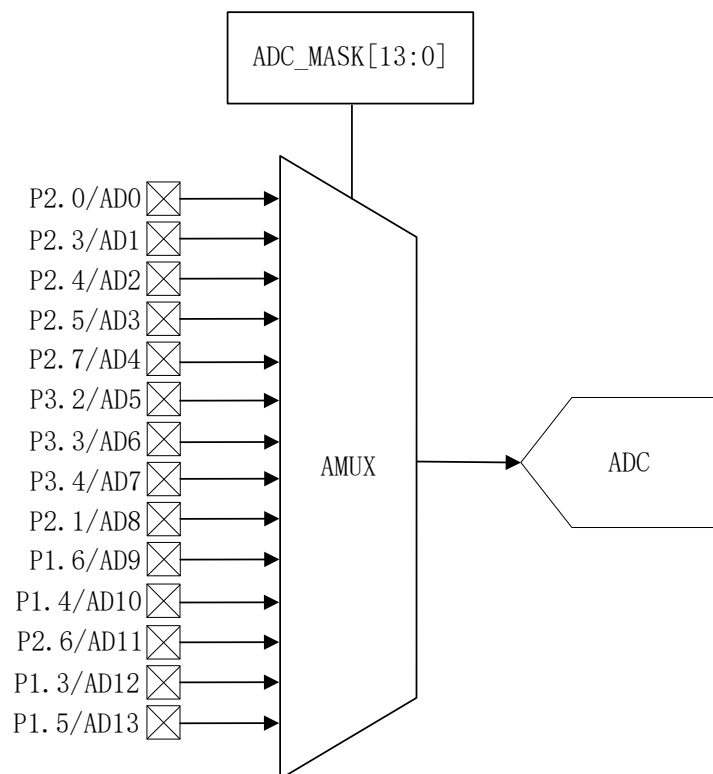


Figure 23-1 ADC Multiplexer Block Diagram

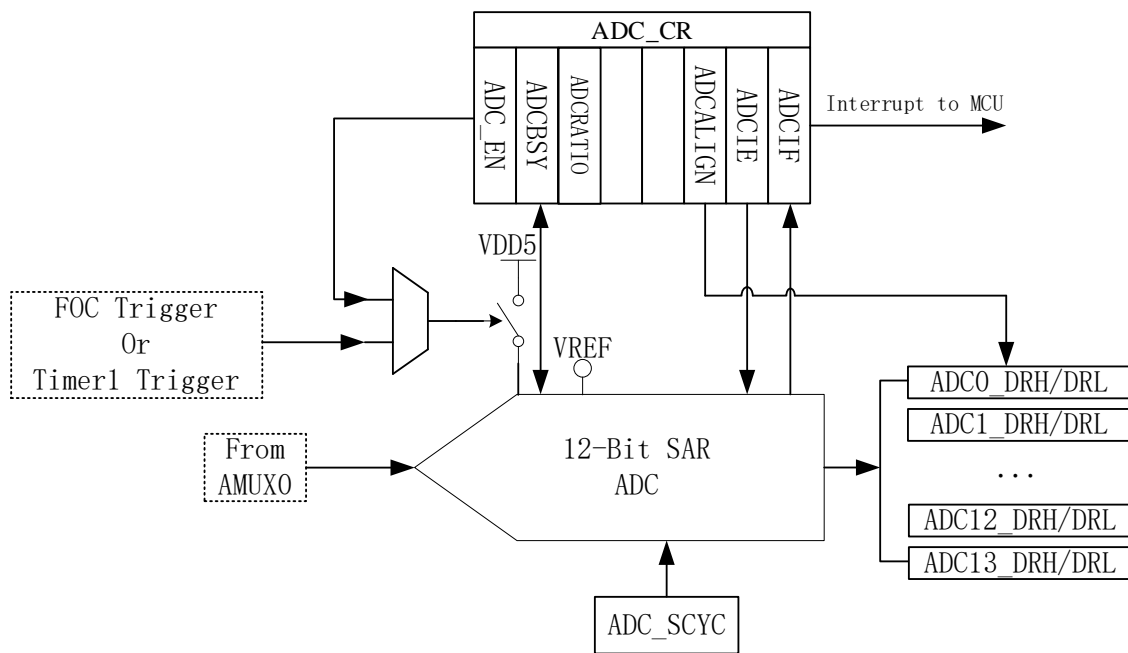


Figure 23-2 ADC Functional Block Diagram

### 23.3 ADC Operations

#### 23.3.1 Sequential Sampling Mode

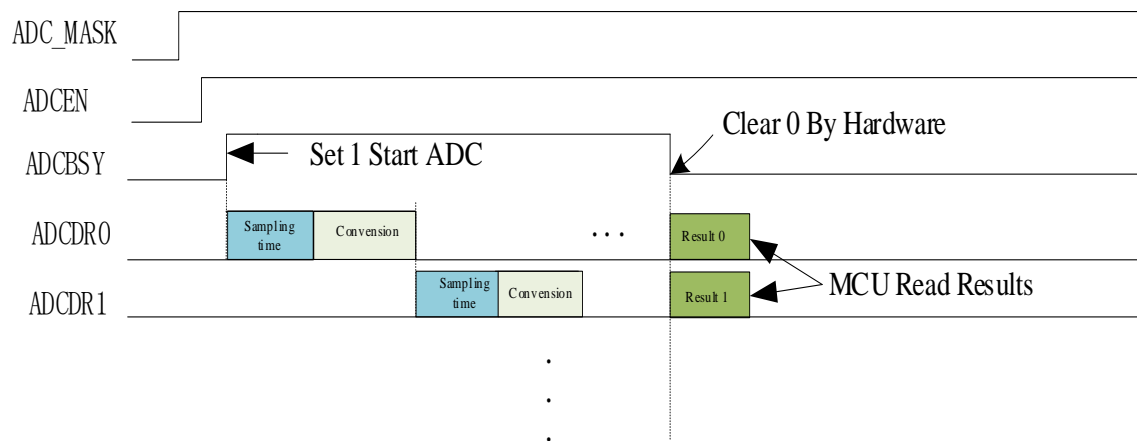


Figure 23-3 ADC Sequential Sampling Timing

ADC operations:

1. Set the appropriate ADC VREF;
2. Configure ADC\_MASK to enable the corresponding channel required to sample;
3. Configure ADC\_SCYC (minimum value is 3) to select the sampling period of each channel;
4. Configure ADC\_CR[ADCEN] = 1 to enable ADC;
5. Configure ADC\_CR[ADCBSY] = 1 to start ADC;

6. When `ADC_CR[ADCBSY] = 0`, ADC results are read by `ADCx_DR`.

Note: The ADC conversion sequence is from low to high based on the enabled channel (i.e., when channel 2/3/4 is enabled, the signal is sampled in order of 2/3/4, and then a single conversion result is read after confirming `ADC_CR[ADCBSY] = 0`).

### 23.3.2 Triggered Sampling Mode

When FOC module is enabled, ADC channel 0/1/2/4 can be used to FOC trigger sampling. Channel 2 is used for bus voltage trigger sampling. In single-shunt current sampling mode, channel 4 is used for itrip sampling. In dual-shunt current sampling mode, channel 0 is used for ia sampling and channel 1 for ib sampling. In triple-shunt current sampling mode, channel 0 is used for ia sampling, channel 1 for ib sampling, and channel 4 for ic sampling.

When Timer1 is enabled, channel 4 is used for bus current sampling. `TIM1_CR3[T1TIS]` is configured to select the input source of position detection as ADC. When `CMP0_CR4[CMP0FS] = 0`, channel 10 is used for U-phase voltage sampling, channel 9 for V-phase voltage sampling, and channel 8 for W-phase voltage sampling. When `CMP0_CR4[CMP0FS] = 1`, channel 10 is used for U-phase voltage sampling, channel 12 for V-phase voltage sampling, and channel 13 for W-phase voltage sampling.

### 23.3.3 Output Data Format

Registers `ADCx_DRH` and `ADCx_DRL` contain the high-order bits and the low-order bits of ADC sampling results. Data can be right-aligned or left-second-high-aligned by configuring `ADC_CR[ADCALIGN]`. When input voltage ranges from 0 to `VREF`, the relation between the input voltage and result data is shown in Table 23-1. The bits, which are not used in `ADCx_DRH` and `ADCx_DRL`, are set to “0”.

Table 23-1 Relation between Input Voltage and Result Data

Input Voltage	Right-aligned	Left-second-high-aligned
0	0x0000	0x0000
VREF/2	0x0800	0x4000
VREF	0x0FFF	0x7FF8

## 23.4 ADC Registers

### 23.4.1 ADC\_CR (0x4039)

Bit	7	6	5	4	3	2	1	0
Name	ADCEN	ADCBSY	RSV			ADCALIGN	ADCIE	ADCIF
Type	R/W	R/W1	-	-	-	R/W	R/W	R/W0
Reset	0	0	-	-	-	0	0	0
Bit	Name	Description						
[7]	ADCEN	ADC Enable 0: Disable 1: Enable						
[6]	ADCBSY	ADC Start & ADC Busy Flag Read: 0: ADC Idle 1: ADC Busy Write: 0: No effect 1: ADC conversion starts Note: Writing "1" to this bit has no effect when ADC_MASK = 0.						
[5:3]	RSV	Reserved						
[2]	ADCALIGN	ADC Data Format Selection 0: ADC output is right-aligned, and ADC result = ADCx_DR[11:0] 1: ADC output is left-second-high-aligned, and ADC result = ADCx_DR[14:3]  Note: The results of triggered sampling mode are always left-second-high-aligned.						
[1]	ADCIE	ADC Interrupt Enable (excluding triggered sampling mode interrupt) 0: Disable 1: Enable						
[0]	ADCIF	ADC Interrupt Flag This bit is set to "1" by hardware when ADC conversion is completed. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to "0". 1: No effect						

### 23.4.2 ADC\_MASK (0x4036, 0x4037)

ADC_MASKH(0x4036)								
Bit	15	14	13	12	11	10	9	8
Name	RSV		CH13EN	CH12EN	CH11EN	CH10EN	CH9EN	CH8EN
Type	-	-	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	-	0	0	0	0	0	0
ADC_MASKL(0x4037)								
Bit	7	6	5	4	3	2	1	0
Name	CH7EN	CH6EN	CH5EN	CH4EN	CH3EN	CH2EN	CH1EN	CH0EN
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:14]	RSV	Reserved						
[13]	CH13EN	ADC Channel 13 Enable						

[12]	CH12EN	ADC Channel 12 Enable
[11]	CH11EN	ADC Channel 11 Enable
[10]	CH10EN	ADC Channel 10 Enable
[9]	CH9EN	ADC Channel 9 Enable
[8]	CH8EN	ADC Channel 8 Enable
[7]	CH7EN	ADC Channel 7 Enable
[6]	CH6EN	ADC Channel 6 Enable
[5]	CH5EN	ADC Channel 5 Enable
[4]	CH4EN	ADC Channel 4 Enable
[3]	CH3EN	ADC Channel 3 Enable
[2]	CH2EN	ADC Channel 2 Enable
[1]	CH1EN	ADC Channel 1 Enable
[0]	CH0EN	ADC Channel 0 Enable

Note: In triggered sampling mode, it is not required to configure ADC\_MASK.

### 23.4.3 DAC\_CR (0x4035)

DAC_CR(0x4035)								
Bit	7	6	5	4	3	2	1	0
Name	DAC0_1EN	DACMOD	ADC_SCYCH[3:0]				DAC2EN	RSV
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	-
Reset	0	0	0	0	1	1	0	-
Bit	Name	Description						
[7]	DAC0_1EN	See section DAC_CR (0x4035) in DAC chapter.						
[6]	DACMOD	See section DAC_CR (0x4035) in DAC chapter.						
[5:2]	ADC_SCYCH[3:0]	ADC Sampling Cycle for ADC Channel 8~13 ADC_SCYCH[3] = 0: The sampling cycle is ADC_SCYCH[2:0] ADC clock cycles. ADC_SCYCH[3] = 1: The sampling cycle is (ADC_SCYCH[2:0]*8 + 7) ADC clock cycles.						
[1]	DAC2EN	See section DAC_CR (0x4035) in DAC chapter.						
[0]	RSV	Reserved						

### 23.4.4 ADC\_SCYC (0x4038)

ADC_SCYC(0x4038)								
Bit	7	6	5	4	3	2	1	0
Name	ADC_SCYC[7:4]				ADC_SCYC[3:0]			
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	1	1	0	0	1	1
Bit	Name	Description						
[7:4]	ADC_SCYC [7:4]	ADC Sampling Cycle for ADC Channel 5~7 and 14 ADC_SCYC[7] = 0: The sampling cycle is ADC_SCYC[6:4] ADC clock cycles ADC_SCYC[7] = 1: The sampling cycle is (ADC_SCYC[6:4]*8 + 7) ADC clock cycles						
[3:0]	ADC_SCYC [3:0]	ADC Sampling Cycle for ADC Channel 0~3 ADC_SCYC[3] = 0: The sampling cycle is ADC_SCYC[2:0] ADC clock cycles ADC_SCYC[3] = 1: The sampling cycle is (ADC_SCYC[2:0]*8 + 7) ADC clock cycles						



**23.4.5 ADC0\_DR (0x0FD8, 0x0FD9)**

ADC0_DRH(0x0FD8)								
Bit	15	14	13	12	11	10	9	8
Name	ADC0_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC0_DRL(0x0FD9)								
Bit	7	6	5	4	3	2	1	0
Name	ADC0_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	ADC0_DR	The conversion results of ADC channel 0 upon completion of ADC conversion in the Sequential Sampling Mode The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.						

**23.4.6 ADC1\_DR (0x0FDA, 0x0FDB)**

ADC1_DRH(0x0FDA)								
Bit	15	14	13	12	11	10	9	8
Name	ADC1_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC1_DRL(0x0FDB)								
Bit	7	6	5	4	3	2	1	0
Name	ADC1_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	ADC1_DR	The conversion results of ADC channel 1 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.						

**23.4.7 ADC2\_DR (0x0FDC, 0x0FDD)**

ADC2_DRH(0x0FDC)								
Bit	15	14	13	12	11	10	9	8
Name	ADC2_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC2_DRL(0x0FDD)								
Bit	7	6	5	4	3	2	1	0
Name	ADC2_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[15:0]	ADC2_DR	The conversion results of ADC channel 2 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.

### 23.4.8 ADC3\_DR (0x0FDE, 0x0FDF)

ADC3_DRH(0x0FDE)								
Bit	15	14	13	12	11	10	9	8
Name	ADC3_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC3_DRL(0x0FDF)								
Bit	7	6	5	4	3	2	1	0
Name	ADC3_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	ADC3_DR	The conversion results of ADC channel 3 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.						

### 23.4.9 ADC4\_DR (0x0FE0, 0x0FE1)

ADC4_DRH(0x0FE0)								
Bit	15	14	13	12	11	10	9	8
Name	ADC4_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC4_DRL(0x0FE1)								
Bit	7	6	5	4	3	2	1	0
Name	ADC4_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	ADC4_DR	The conversion results of ADC channel 4 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.						

**23.4.10 ADC5\_DR (0x0FE2, 0x0FE3)**

ADC5_DRH(0x0FE2)								
Bit	15	14	13	12	11	10	9	8
Name	ADC5_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC5_DRL(0x0FE3)								
Bit	7	6	5	4	3	2	1	0
Name	ADC5_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	ADC5_DR	The conversion results of ADC channel 5 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.						

**23.4.11 ADC6\_DR (0x0FE4, 0x0FE5)**

ADC6_DRH(0x0FE4)								
Bit	15	14	13	12	11	10	9	8
Name	ADC6_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC6_DRL(0x0FE5)								
Bit	7	6	5	4	3	2	1	0
Name	ADC6_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	ADC6_DR	The conversion results of ADC channel 6 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.						

**23.4.12 ADC7\_DR (0x0FE6, 0x0FE7)**

ADC7_DRH(0x0FE6)								
Bit	15	14	13	12	11	10	9	8
Name	ADC7_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC7_DRL(0x0FE7)								
Bit	7	6	5	4	3	2	1	0
Name	ADC7_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[15:0]	ADC7_DR	The conversion results of ADC channel 7 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.

### 23.4.13 ADC8\_DR (0x0FE8, 0x0FE9)

ADC8_DRH(0x0FE8)								
Bit	15	14	13	12	11	10	9	8
Name	ADC8_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC8_DRL(0x0FE9)								
Bit	7	6	5	4	3	2	1	0
Name	ADC8_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	ADC8_DR	The conversion results of ADC channel 8 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.						

### 23.4.14 ADC9\_DR (0x0FEA, 0x0FEB)

ADC9_DRH(0x0FEA)								
Bit	15	14	13	12	11	10	9	8
Name	ADC9_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC9_DRL(0x0FEB)								
Bit	7	6	5	4	3	2	1	0
Name	ADC9_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	ADC9_DR	The conversion results of ADC channel 9 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.						

### 23.4.15 ADC10\_DR (0x0FEC, 0x0FED)

ADC10_DRH(0x0FEC)								
Bit	15	14	13	12	11	10	9	8
Name	ADC10_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0

ADC10_DRL(0x0FED)								
Bit	7	6	5	4	3	2	1	0
Name	ADC10_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	ADC10_DR	The conversion results of ADC channel 10 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.						

#### 23.4.16 ADC11\_DR (0x0FEE, 0x0FEF)

ADC11_DRH(0x0FEE)								
Bit	15	14	13	12	11	10	9	8
Name	ADC11_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC11_DRL(0x0FEF)								
Bit	7	6	5	4	3	2	1	0
Name	ADC11_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	ADC11_DR	The conversion results of ADC channel 11 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.						

#### 23.4.17 ADC12\_DR (0x0FF0, 0x0FF1)

ADC12_DRH(0x0FF0)								
Bit	15	14	13	12	11	10	9	8
Name	ADC12_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC12_DRL(0x0FF1)								
Bit	7	6	5	4	3	2	1	0
Name	ADC12_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	ADC12_DR	The conversion results of ADC channel 12 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].  Note: ADC results of Triggered Sampling Mode are not updated to this register.						

**23.4.18 ADC13\_DR (0x0FF2, 0x0FF3)**

ADC13_DRH(0x0FF2)								
Bit	15	14	13	12	11	10	9	8
Name	ADC13_DR[15:8]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
ADC13_DRL(0x0FF3)								
Bit	7	6	5	4	3	2	1	0
Name	ADC13_DR[7:0]							
Type	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[15:0]	ADC13_DR	<p>The conversion results of ADC channel 13 upon completion of ADC conversion in the Sequential Sampling Mode. The data is aligned according to ADC_CR[ADCALIGN].</p> <p>Note: ADC results of Triggered Sampling Mode are not updated to this register.</p>						

## 24 DAC

### 24.1 DAC Introduction

The chip integrates three DAC modules, where DAC0 is a 9-bit digital-to-analog converter, DAC1 is a 6-bit digital-to-analog converter and DAC2 is a 8-bit digital-to-analog converter

### 24.2 DAC0 Functional Block Diagram

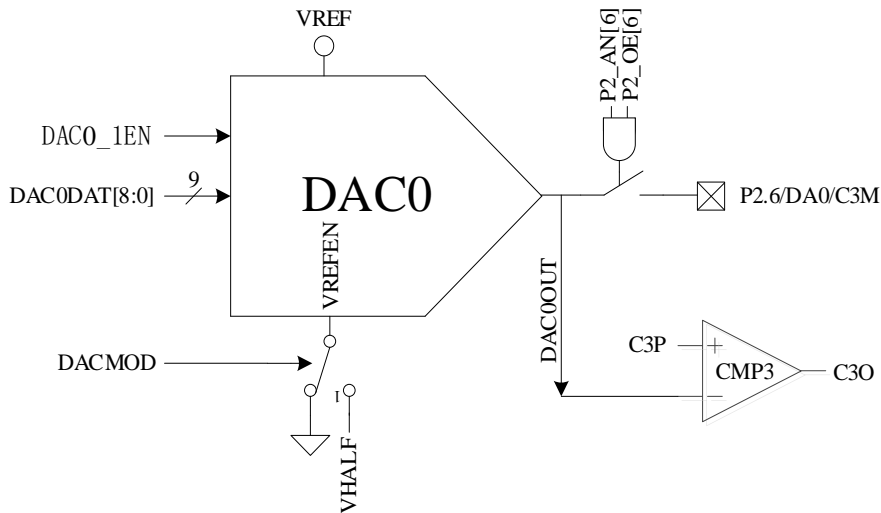


Figure 24-1 DAC0 Functional Block Diagram

As shown in Figure 24-1, DAC0 converts 9-bit digital data into analog voltage and sends the voltage to CMP3 negative input for bus over-current protection. P2.6 pin can be configured as the analog output.

Note: DAC0 output has no current drive capability and can only carry capacitive load. To carry resistive load, operational amplifiers are used to follow the voltage output.

DAC0 operations are as follows:

1. Configure  $P2\_AN[6] = 1$  and  $P2\_OE[6] = 1$ , and DAC0 output to P2.6 pin;
2. Configure  $VREF\_CR[VREFEN] = 1$  and  $DAC\_CR[DAC0\_1EN] = 1$ , and VREF is used as DAC0 reference voltage;
3. The range of output voltage is set by  $DAC\_CR[DACMOD]$ . When  $DAC\_CR[DACMOD] = 0$ , full-voltage output mode is active, and the range of output voltage is  $0 \sim VREF$ . When  $DAC\_CR[DACMOD] = 1$ , half-voltage output mode is active, the range of output voltage is  $VHALF \sim VREF$ . Output voltage of DAC0DAT under different configuration is shown in Table 24-1.

Table 24-1 Output Voltage of DAC0 under Different Configurations

DAC0DAT[8:0]	DAC Output Voltage ( $DAC\_CR[DACMOD] = 0$ )	DAC Output Voltage ( $DAC\_CR[DACMOD] = 1$ )
0x000	0	VHALF
0x100	$VREF/2$	$(VREF - VHALF)/2 + VHALF$
0x1FF	$VREF * 511/512$	$(VREF - VHALF) * 511/512 + VHALF$

### 24.3 DAC1 Functional Block Diagram

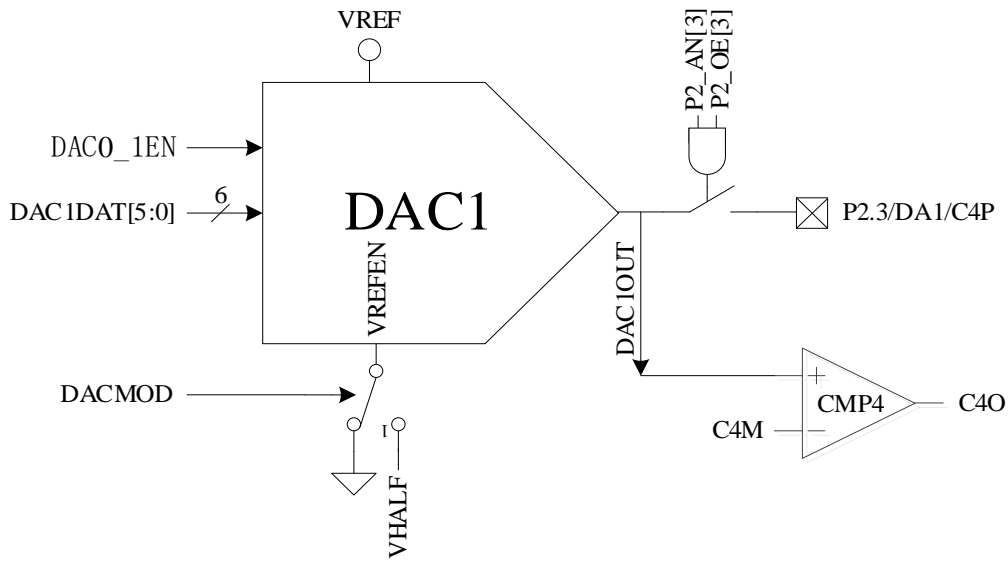


Figure 24-2 DAC1 Functional Block Diagram

As shown in Figure 24-2, DAC1 converts 6-bit digital data into analog voltage, and sends the voltage to CMP4 positive input for cycle-by-cycle current limiting. P2.3 can be configured as the output pin.

Note: DAC1 output has no current drive capability and can only carry capacitive load. To carry resistive load, operational amplifiers are used to follow the voltage output.

DAC1 operations are as follows:

1. Configure P2\_AN[3] = 1 and P2\_OE[3] = 1, and DAC1 output to P2.3 pin;
2. Configure VREF\_CR[VREFEN] = 1 and DAC\_CR[DAC0\_1EN] = 1, and VREF is used as DAC1 reference voltage;
3. The range of output voltage is set by DAC\_CR[DACMOD]. When DAC\_CR[DACMOD] = 0, full-voltage output mode is active, and the range of output voltage is 0~VREF. When DAC\_CR[DACMOD] = 1, half-voltage output mode is active, and the range of output voltage is VHALF~VREF. Output voltage of DAC1 under different configurations is shown in Table 24-2.

Table 24-2 Output Voltage of DAC1 under Different Configurations

DAC1DAT[5:0]	DAC Output Voltage (DAC_CR[DACMOD] = 0)	DAC Output Voltage (DAC_CR[DACMOD] = 1)
0x00	0	VHALF
0x20	VREF/2	(VREF - VHALF)/2 + VHALF
0x3F	VREF*63/64	(VREF - VHALF)*63/64 + VHALF



## 24.4 DAC2 Functional Block Diagram

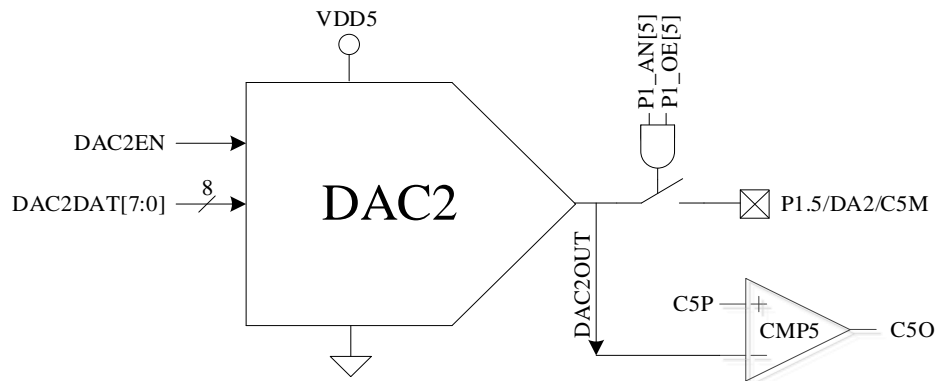


Figure 24-3 DAC2 Functional Block Diagram

As shown in Figure 24-3, DAC2 converts 8-bit digital data into analog voltage, and sends the voltage to CMP5 positive input for cycle-by-cycle current limiting. P1.5 can be configured as the output pin.

Note: DAC2 output has no current drive capability and can only carry capacitive load. To carry resistive load, operational amplifiers are used to follow the voltage output.

DAC1 operations are as follows:

1. Configure P1\_AN[5] = 1 and P1\_OE[5] = 1, and DAC2 output to P1.5/DA2 pin;
2. Configure VREF\_CR[VREFEN] = 1 and DAC\_CR[DAC2EN] = 1 to enable DAC2, and VREF is used as DAC2 reference voltage.

Table 24-3 Output Voltage of DAC2 under Different Configurations

DAC2DAT[7:0]	DAC Output Voltage
0x00	0
0x80	VREF/2
0xFF	VREF*255/256

## 24.5 DAC Registers

### 24.5.1 DAC\_CR (0x4035)

Bit	7	6	5	4	3	2	1	0
Name	DAC0_1EN	DACMOD	ADC_SCYCH[3:0]			DAC2EN	RSV	
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	-
Reset	0	0	0	0	1	1	0	-
Bit	Name	Description						
[7]	DAC0_1EN	DAC0, DAC1 Enable 0: Disable 1: Enable						
[6]	DACMOD	DAC Mode Setting 0: Full-voltage Output Mode 1: Half-voltage Output Mode						
[5:2]	ADC_SCYCH[3:0]	See section DAC_CR (0x4035) in ADC chapter.						

[1]	DAC2EN	DAC2 Enable 0: Disable 1: Enable
[0]	RSV	Reserved

### 24.5.2 DAC0\_DR (0x404B)

Bit	7	6	5	4	3	2	1	0
Name	DAC0DAT[8:1]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	DAC0DAT[8:1]	8 high-order bits input of DAC0 controller						

### 24.5.3 DAC1\_DR (0x404A)

Bit	7	6	5	4	3	2	1	0
Name	DAC0_DR_0	RSV	DAC1DAT					
Type	R/W	-	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	-	0	0	0	0	0	0
Bit	Name	Description						
[7]	DAC0_DR_0	LSB input of DAC0 controller						
[6]	RSV	Reserved						
[5:0]	DAC1DAT	6-bit data input of DAC1 controller						

### 24.5.4 DAC2\_DR (0x4049)

Bit	7	6	5	4	3	2	1	0
Name	DAC2DAT							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	DAC2DAT	8-bit data input of DAC2 controller						

## 25 DMA

### 25.1 DMA Instructions

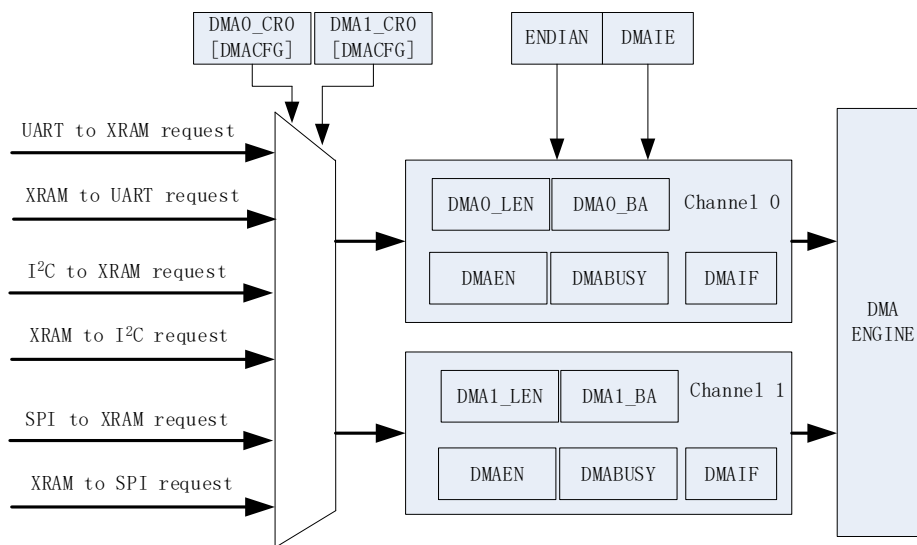


Figure 25-1 DMA Functional Block Diagram

The DMA module is a dual-channel DMA controller, which performs direct data transfer between peripherals (SPI, UART, I<sup>2</sup>C) and XRAM (IRAM data invalid). DMA accessing to XRAM does not interfere with the normal CPU read/write operation to XRAM. The length of the transferred data and the start address of XRAM access is configurable. Data transfer mode is configurable and interrupt can be enabled.

DMA instructions are as follows:

1. Configure and enable the peripheral, and set input and output channels taken over by DMA by DMA<sub>x</sub>\_CR0[DMACFG];
2. Configure DMA interrupt enable, transfer order, transfer length and XRAM start address. Write “1” to DMA<sub>x</sub>\_CR0[DMAEN] and DMA<sub>x</sub>\_CR0[DMABSY] to start DMA;
3. After data transfer, the interrupt flag bit DMA<sub>x</sub>\_CR0[DMAIF] is set to “1” by hardware and it is cleared to “0” by software;
4. Set DMA<sub>x</sub>\_CR0[DMABSY] to “1” to start DMA again.

### 25.2 DMA Registers

#### 25.2.1 DMA0\_CR0 (0x403A)

Bit	7	6	5	4	3	2	1	0
Name	DMAEN	DMABSY	DMACFG			DMAIE	ENDIAN	DMAIF
Type	R/W	R/W1	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	DMAEN	DMA Channel 0 Enable 0: Disable 1: Enable						

[6]	DMABSY	DMA Channel 0 Start/Busy Flag Read: 0: Channel 0 Idle 1: Channel 0 Busy Write: 0: No effect 1: Channel 0 starts for data transfer
[5:3]	DMACFG	DMA Channel 0 Peripherals and Transfer Direction Selection  000: From UART1 to XRAM 001: From XRAM to UART1 010: From I <sup>2</sup> C to XRAM 011: From XRAM to I <sup>2</sup> C 100: From SPI to XRAM 101: From XRAM to SPI 110: From UART2 to XRAM 111: From XRAM to UART2  Note: It cannot be configured when Channel 0 is busy.
[2]	DMAIE	DMA Interrupt Enable 0: Disable 1: Enable
[1]	ENDIAN	DMA Data Transfer Sequence 0: High bytes are received or sent first 1: Low bytes are received or sent first  Note: This bit is set for 16-bit data mode, and shall be configured to “0” for 8-bit data mode. It cannot be configured when Channel 0 or 1 is busy.
[0]	DMAIF	DMA Channel 0 Transfer Interrupt Event Flag Bit Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: The interrupt event is generated.

### 25.2.2 DMA1\_CR0 (0x403B)

Bit	7	6	5	4	3	2	1	0
Name	DMAEN	DMABSY	DMACFG			DBGSW	DBGEN	DMAIF
Type	R/W	R/W1	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	DMAEN	DMA Channel 1 Enable 0: Disable 1: Enable						
[6]	DMABSY	DMA Channel 1 Start/Busy Read: 0: Channel 1 Idle 1: Channel 1 Busy Write: 0: No effect 1: Channel 1 starts for data transfer						
[5:3]	DMACFG	DMA Channel 1 Peripherals and Direction Selection 000: From UART1 to XRAM 001: From XRAM to UART1 010: From I <sup>2</sup> C to XRAM 011: From XRAM to I <sup>2</sup> C						

		100: From SPI to XRAM 101: From XRAM to SPI 110: From UART2 to XRAM 111: From XRAM to UART2  Note: It cannot be configured when Channel 1 is busy.
[2]	DBGSW	Sector Targeted in Debug Mode 0: XSFR as the Debug area (export address space: 0x4020 ~ 0x40FF) 1: XRAM as the Debug area (export address space: 0x0000 ~ 0x0317)
[1]	DBGEN	Debug Mode Enable DMA works in Debug mode when DMA1_CR0[DMACFG] is set to “101” and DMA1_CR0[DBGEN] to “1”. After SPI is enabled, DMA automatically sends relevant data in the sector defined by DMA1_CR0[DBGSW] via MOSI. DMA1_BA/DMA1_LEN defines the start address and range of the relevant data. 0: Disable 1: Enable  Note: DMA Channel 1 Interrupt is automatically disabled in Debug mode.
[0]	DMAIF	DMA Channel 1 Transfer Interrupt Event Flag Bit Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: The interrupt event is generated.

### 25.2.3 DMA0\_LEN (0x403C)

Bit	7	6	5	4	3	2	1	0
Name	RSV		DMA0_LEN					
Type	-	-	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	-	0	0	0	0	0	0

Bit	Name	Description
[7:6]	RSV	Reserved
[5:0]	DMA0_LEN	Transfer Length of DMA Channel 0 Read: The number of the byte that is currently transferred by DMA Channel 0 (0 denotes the first byte) Write: XRAM data transfer length of DMA Channel 0  Note: It cannot be configured when Channel 0 is busy. When DMA0_CR0[ENDIAN] = 1 (low bytes are received or transmitted first) , it is recommended that DMA0_LEN be set to an odd number.

### 25.2.4 DMA0\_BA (0x403E, 0x403F)

DMA0_BAH(0x403E)								
Bit	15	14	13	12	11	10	9	8
Name	RSV				DMA0_BA[11:8]			
Type	-	-	-	-	R/W	R/W	R/W	R/W
Reset	-	-	-	-	0	0	0	0

DMA0_BAL(0x403F)								
Bit	7	6	5	4	3	2	1	0
Name	DMA0_BA[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[15:12]	RSV	Reserved
[11:0]	DMA0_BA	Start address of data transfer by DMA Channel 0 Start address of XRAM data transfer by DMA Channel 0 It cannot be configured when Channel 0 is busy.  Note: XRAM address space for data transfer by Channel 0: DMA0_BA[11:0] ~ (DMA0_BA[11:0] + DMA0_LEN[5:0])

### 25.2.5 DMA1\_LEN (0x403D)

Bit	7	6	5	4	3	2	1	0
Name	RSV		DMA1_LEN					
Type	-	-	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	-	0	0	0	0	0	0

Bit	Name	Description
[7:6]	RSV	Reserved
[5:0]	DMA1_LEN	Transfer length of DMA Channel 1 Read: The number of the bytes that is currently transferred by DMA Channel 1 (0 denotes the first byte) Write: XRAM data transfer length of DMA Channel 1 Note: It cannot be configured when Channel 1 is busy. When DMA0_CR0[ENDIAN] = 1 (low bytes are received or transmitted first), it is recommended that DMA1_LEN be set to an odd number.

### 25.2.6 DMA1\_BA (0x4040, 0x4041)

DMA1_BAH(0x4040)								
Bit	15	14	13	12	11	10	9	8
Name	RSV				DMA1_BA[11:8]			
Type	-	-	-	-	R/W	R/W	R/W	R/W
Reset	-	-	-	-	0	0	0	0

DMA1_BAL(0x4041)								
Bit	7	6	5	4	3	2	1	0
Name	DMA1_BA[7:0]							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit	Name	Description
[15:12]	RSV	Reserved
[11:0]	DMA1_BA	Start address of data transfer by DMA Channel 1 Start address of XRAM data transfer by DMA Channel 1 It cannot be configured when Channel 1 is busy. Note: XRAM address space for data transfer by Channel 1: DMA1_BA[11:0] ~ (DMA1_BA[11:0] + DMA1_LEN[5:0])

Note: When I<sup>2</sup>C is selected as DMA channel peripherals (including from I<sup>2</sup>C to XRAM and from XRAM to I<sup>2</sup>C), START + Address interrupt of I<sup>2</sup>C communication still requires to be cleared to “0” by MCU software. In I<sup>2</sup>C slave mode, if STOP is received, I2C\_SR[I2CSTP] = 0 is configured to clear I<sup>2</sup>C interrupt and restart the DMA transfer.

## 26 VREF

### 26.1 VREF Instructions

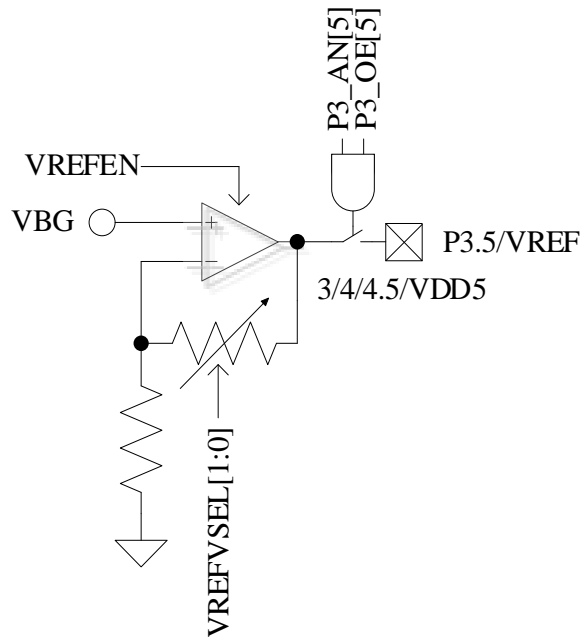


Figure 26-1 I/O Pins of VREF Module

The input and output ports of the VREF module are shown in Figure 26-1. VREF is the voltage reference generation block that provides internal voltage reference to ADC and DAC modules. VBG is the voltage supplied by the chip internally.

VREF is enabled when VREF\_CR[VREFEN] is set to “1”. The output voltage is selected by configuring VREF\_CR[VREFVSEL]. When P3\_AN[5] = 1 and P3\_OE[5] = 1, VREF is output to P3.5 pin.

## 26.2 VREF Register

### 26.2.1 VREF\_CR (0x404F)

Bit	7	6	5	4	3	2	1	0
Name	VREFVSEL		RSV	VREFEN	RSV	VHALFSEL		VHALFEN
Type	R/W	R/W	-	R/W	-	R/W	R/W	R/W
Reset	0	0	-	0	-	1	1	0
Bit	Name	Description						
[7:6]	VREFVSEL	VREF Module Output Voltage Selection 00: 4.5V 01: VDD5 10: 3V 11: 4V						
[5]	RSV	Reserved						
[4]	VREFEN	VREF Module Enable Bit 0: Disable. P3_AN[5] is set to "1", and external VREF is input from P3.5 pin 1: Enable. P3_AN[5] is set to "1", and internal VREF is output to P3.5 pin. A 0.1μF ~ 1μF external capacitor is added to improve the stability of VREF.						
[3]	RSV	Reserved						
[2:1]	VHALFSEL	VHALF Operating Voltage Selection (VREF Coefficient) 00: 1/8 01: 1/4 10: 25/64 11: 1/2 (Default)						
[0]	VHALFEN	VHALF Enable 0: Disable 1: Enable						



## 27 VHALF

### 27.1 VHALF Instructions

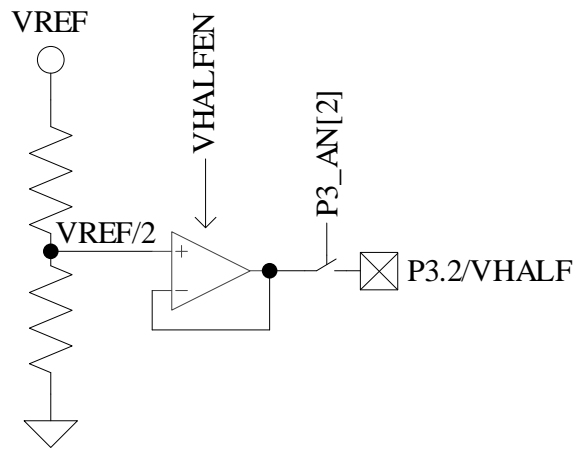


Figure 27-1 I/O Pins of VHALF Module

The input and output ports of VHALF module are shown in Figure 27-1. This module generates the voltage reference. Its voltage value is controlled by register VREF\_CR[VHALFSEL], as detailed: 00: VREF/8; 01: VREF/4; 10: VREF\*25/64; 11: VREF/2 (Default)

VHALF is enabled when VREF\_CR[VHALFEN] is set to “1”, and the voltage is output to P3.2. A 1 $\mu$ F external capacitor is added.

### 27.2 VHALF Register

See VREF\_CR (0x404F) for details.

## 28 Operational Amplifier

### 28.1 Operational Amplifier Introduction

The chip integrates four high-speed independent operational amplifiers, AMP0, AMP1, AMP2 and AMP3. Each operational amplifier has a separate enable bit, and can be configured as PGA.

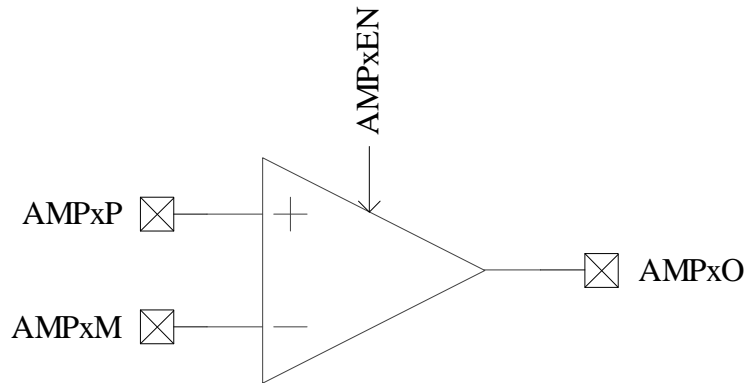


Figure 28-1 Schematic Diagram of Operational Amplifier Module

### 28.2 Operational Amplifier Instructions

#### 28.2.1 Bus Current Sampling Operational Amplifier (AMP0)

AMP0 operates in three modes: normal mode, PGA differential input mode and PGA single-ended input mode.

##### 28.2.1.1 AMP0 Normal Mode

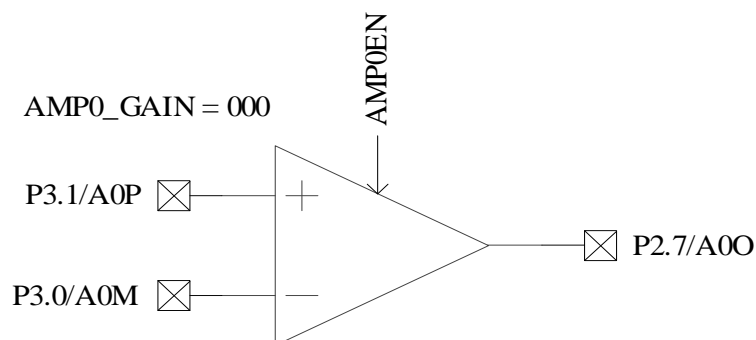


Figure 28-2 Bus Current AMP0

The I/O pins of AMP0 are shown in Figure 28-2. AMP0 is enabled when  $AMP\_CR0[AMP0EN] = 1$ , and P2.7, P3.0 and P3.1 are automatically configured to analog signal mode by the hardware.

### 28.2.1.2 AMP0 PGA Differential Input Mode

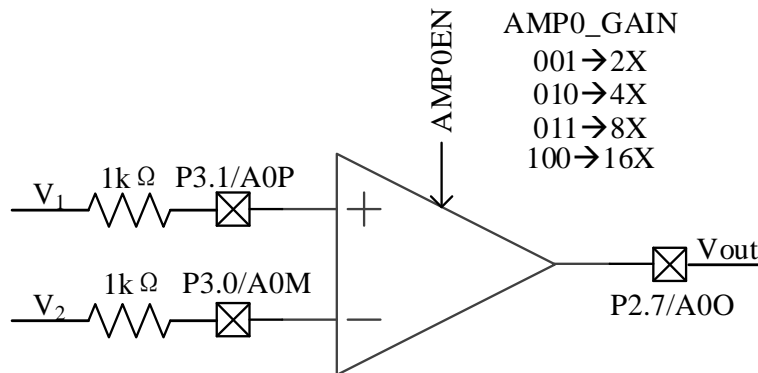


Figure 28-3 AMP0 Operating in PGA Differential Input Mode

As shown in Figure 28-3, positive and negative inputs of AMP0 are connected with a 1kΩ resistor in the external circuit respectively. When PGA differential Input Mode is selected for AMP0, the amplification gain is set by AMP\_CR1[AMP0\_GAIN], and AMP0 is enabled when AMP\_CR0[AMP0EN] = 1. The relation between output and input of operational amplifier:  $V_{out} = V_{HALF} + (V_1 - V_2) * AMP0\_GAIN$ .

### 28.2.1.3 AMP0 PGA Single-ended Input Mode

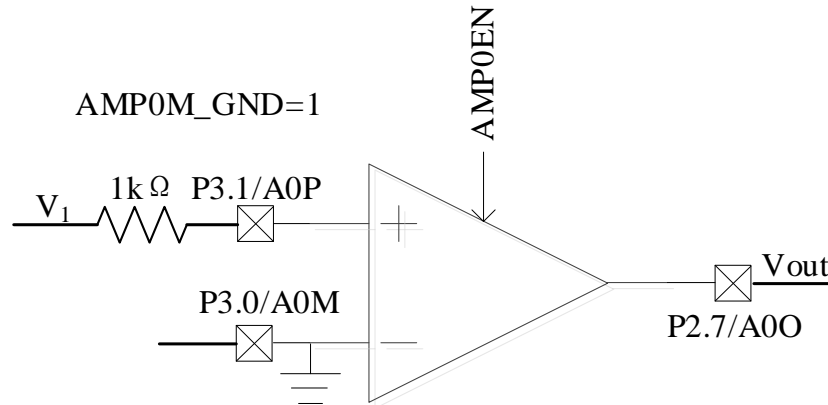


Figure 28-4 AMP0 Operating in PGA Single-ended Input Mode

As shown in Figure 28-4, positive input of AMP0 is connected with a 1kΩ resistor in the external circuit, and negative input is connected to the ground inside MCU. When PGA Single-ended Input Mode is selected for AMP0, the amplification gain is set by AMP\_CR1[AMP0\_GAIN], and AMP0 is enabled when AMP\_CR0[AMP0EN] = 1. The relation between output and input of operational amplifier:

When AMP\_CR1[AMP0\_GAIN] is set as 2x,  $V_{out} = 7/6 * V_{HALF} + 7/3 * V_1$

When AMP\_CR1[AMP0\_GAIN] is set as 4x,  $V_{out} = 6/5 * V_{HALF} + 24/5 * V_1$

When AMP\_CR1[AMP0\_GAIN] is set as 8x,  $V_{out} = 11/9 * V_{HALF} + 88/9 * V_1$

When AMP\_CR1[AMP0\_GAIN] is set as 16x,  $V_{out} = 21/17 * V_{HALF} + 336/17 * V_1$

## 28.2.2 Phase Current Operational Amplifier (AMP1/AMP2)

### 28.2.2.1 AMP1 Normal Mode

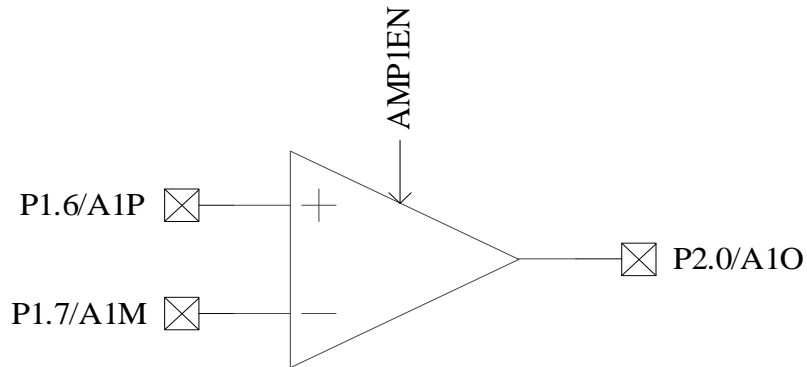


Figure 28-5 AMP1 I/O Pins

The I/O pins of AMP1 are shown in Figure 28-5. AMP1 is enabled when AMP\_CR0[AMP1EN] = 1. P1.6, P1.7 and P2.0 pins are automatically configured to analog signal mode by the hardware. P1\_AN[7:6] is set to “11” and P2\_AN[0] to “1”.

### 28.2.2.2 AMP2 Normal Mode

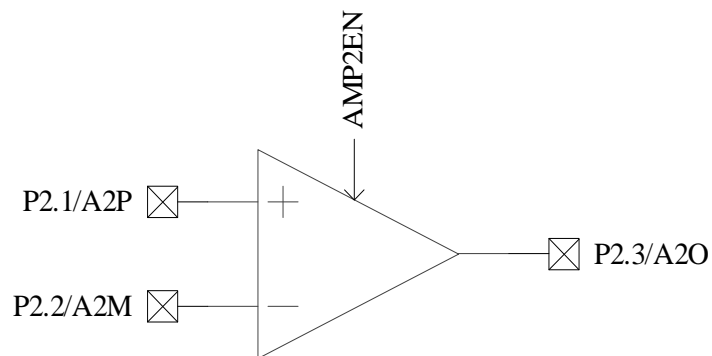


Figure 28-6 AMP2 I/O Pins

The I/O pins of AMP2 are shown in Figure 28-6. AMP2 is enabled when AMP\_CR0[AMP2EN] = 1. P2.1, P2.2 and P2.3 are automatically configured to analog signal mode by the hardware. P2\_AN[3:1] is set to “111”.

### 28.2.2.3 AMP1 PGA Differential Input Mode

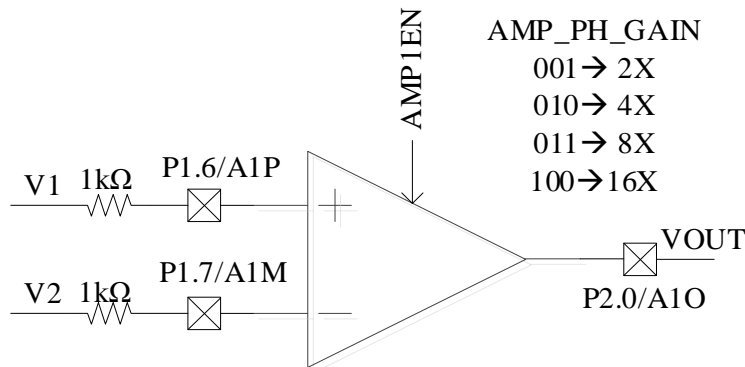


Figure 28-7 AMP1 Operating in PGA Differential Input Mode

As shown in Figure 28-7, positive and negative inputs of AMP1 are connected with a 1kΩ resistor in the external circuit respectively. When PGA Differential Input Mode is selected for AMP1, the amplification gain is set by AMP\_CR1[AMP\_PH\_GAIN], and AMP1 is enabled when AMP\_CR0[AMP1EN] = 1. The relation between output and input of operational amplifier:  $V_{out} = V_{HALF} + (V_1 - V_2) * AMP\_PH\_GAIN$ .

### 28.2.2.4 AMP2 PGA Differential Input Mode

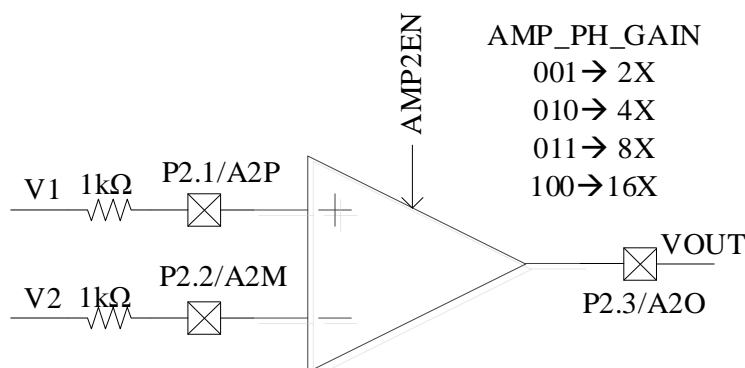


Figure 28-8 AMP2 Operating in PGA Differential Input Mode

As shown in Figure 28-8, positive and negative inputs of AMP2 are connected with a 1kΩ resistor in the external circuit respectively. When PGA Differential Input Mode is selected for AMP2, the amplification gain is set by AMP\_CR1[AMP\_PH\_GAIN]. AMP2 is enabled when AMP\_CR0[AMP2EN] = 1. The relation between output and input of operational amplifier:  $V_{out} = V_{HALF} + (V_1 - V_2) * AMP\_PH\_GAIN$ .

### 28.2.2.5 AMP1 PGA Single-ended Input Mode

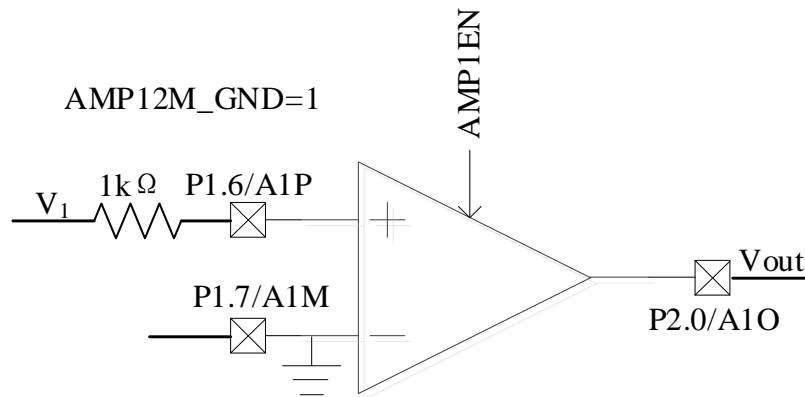


Figure 28-9 AMP1 Operating in PGA Single-ended Input Mode

As shown in Figure 28-9, positive input of AMP1 is connected with a 1kΩ resistor in the external circuit, and negative input is connected to the ground inside MCU. When PGA Single-ended Input Mode is selected for AMP1, the amplification gain is set by AMP\_CR1[AMP\_PH\_GAIN]. AMP1 is enabled by configuring AMP\_CR0[AMP12M\_GND] = 1 and AMP\_CR0[AMP1EN] = 1. The relation between output and input of operational amplifier:

When AMP\_CR1[AMP\_PH\_GAIN] is set as 2x,  $V_{out} = 7/6 * V_{HALF} + 7/3 * V_1$

When AMP\_CR1[AMP\_PH\_GAIN] is set as 4x,  $V_{out} = 6/5 * V_{HALF} + 24/5 * V_1$

When AMP\_CR1[AMP\_PH\_GAIN] is set as 8x,  $V_{out} = 11/9 * V_{HALF} + 88/9 * V_1$

When AMP\_CR1[AMP\_PH\_GAIN] is set as 16x,  $V_{out} = 21/17 * V_{HALF} + 336/17 * V_1$

### 28.2.2.6 AMP2 PGA Single-ended Input Mode

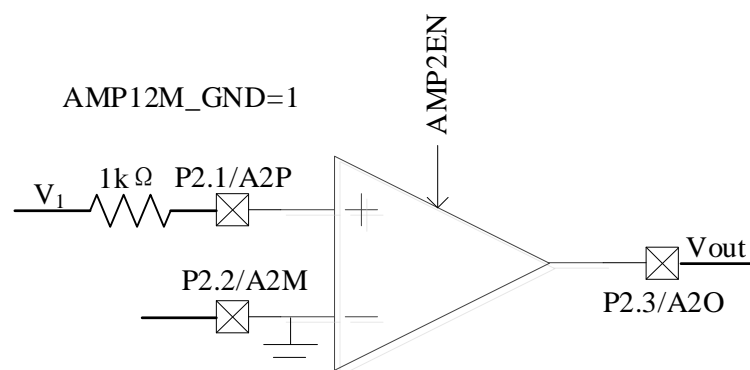


Figure 28-10 AMP2 Operating in PGA Single-ended Input Mode

As shown in Figure 28-10, positive input of AMP2 is connected with a 1kΩ resistor in the external circuit, and negative input is connected to the ground inside MCU. When PGA Single-ended Input Mode is selected for AMP2, the amplification gain is set by AMP\_CR1[AMP\_PH\_GAIN], and AMP2 is enabled by

configuring AMP\_CR0 [AMP12M\_GND] = 1 and AMP\_CR0[AMP2EN] = 1. The relation between output and input of operational amplifier:

When AMP\_CR1[AMP\_PH\_GAIN] is set as 2x,  $V_{out} = 7/6 * V_{HALF} + 7/3 * V_1$

When AMP\_CR1[AMP\_PH\_GAIN] is set as 4x,  $V_{out} = 6/5 * V_{HALF} + 24/5 * V_1$

When AMP\_CR1[AMP\_PH\_GAIN] is set as 8x,  $V_{out} = 11/9 * V_{HALF} + 88/9 * V_1$

When AMP\_CR1[AMP\_PH\_GAIN] is set as 16x,  $V_{out} = 21/17 * V_{HALF} + 336/17 * V_1$

### 28.2.3 Operational Amplifier AMP3

AMP3 works in three modes: normal mode, PGA differential input mode and PGA single-ended input mode.

#### 28.2.3.1 AMP3 Normal Mode

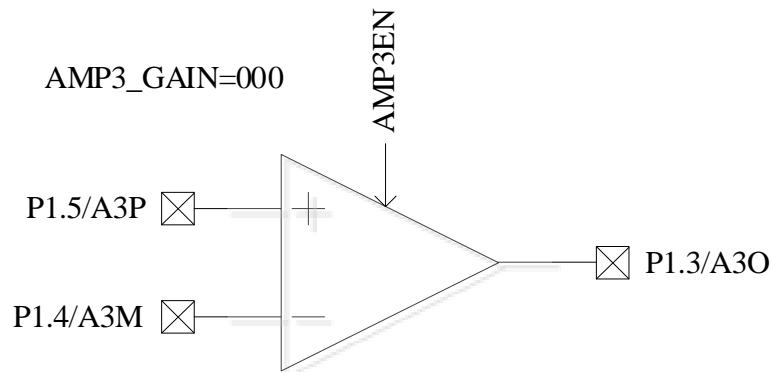


Figure 28-11 AMP3 I/O Pins

The I/O pins of AMP3 are shown in Figure 28-11. AMP3 is enabled when AMP\_CR0[AMP3EN] = 1, and P1.5, P1.4 and P1.3 are automatically configured to analog input mode by the hardware. P1\_AN[5:4] is set to "11", P1\_AN[HBMOD] to "1", and P1\_OE[3] to "1".

#### 28.2.3.2 AMP3 PGA Differential Input Mode

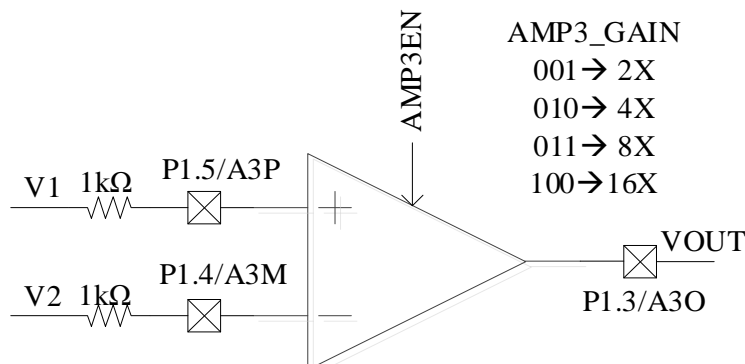


Figure 28-12 AMP3 Operating in PGA Differential Input Mode

As shown in Figure 28-12, positive and negative inputs of AMP3 are connected with a 1kΩ resistor in the external circuit respectively. When PGA Single-ended Input Mode is selected for AMP3, the amplification gain is set by AMP\_CR2[AMP3\_GAIN], and AMP3 is enabled when AMP\_CR0[AMP3EN] = 1. The relation between output and input of operational amplifier:  $V_{out} = V_{HALF} + (V_1 - V_2) * AMP3\_GAIN$ .

### 28.2.3.3 AMP3 PGA Single-ended Input Mode

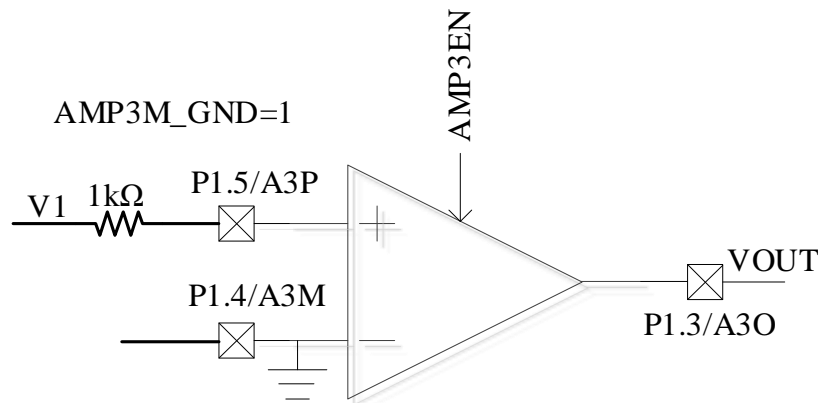


Figure 28-13 AMP3 Operating in PGA Single-ended Input Mode

As shown in Figure 28-13, positive input of AMP3 is connected with a 1kΩ resistor in the external circuit, and negative input is connected to the ground inside MCU. When PGA Single-ended Input Mode is selected for AMP3, the amplification gain is set by AMP\_CR2[AMP3\_GAIN], and AMP3 is enabled when AMP\_CR0[AMP3EN] = 1. The relation between output and input of operational amplifier:

When AMP\_CR2[AMP3\_GAIN] is set as 2x,  $V_{out} = 7/6 * V_{HALF} + 7/3 * V1$

When AMP\_CR2[AMP3\_GAIN] is set as 4x,  $V_{out} = 6/5 * V_{HALF} + 24/5 * V1$

When AMP\_CR2[AMP3\_GAIN] is set as 8x,  $V_{out} = 11/9 * V_{HALF} + 88/9 * V1$

When AMP\_CR2[AMP3\_GAIN] is set as 16x,  $V_{out} = 21/17 * V_{HALF} + 336/17 * V1$



## 28.3 Operational Amplifier Registers

### 28.3.1 AMP\_CR0 (0x404E)

Bit	7	6	5	4	3	2	1	0
Name	RSV	AMP3M_GND	AMP12M_GND	AMP0M_GND	AMP3EN	AMP2EN	AMP1EN	AMP0EN
Type	-	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	0	0	0	0	0	0	0

Bit	Name	Description
[7]	RSV	Reserved
[6]	AMP3M_GND	Enable the negative input of AMP3, after which the built-in P1.4 pin is wired to GND 0: Disable 1: Enable
[5]	AMP12M_GND	Enable the negative input of AMP1&2, after which the built-in P1.7 &P2.2 pins are wired to GND 0: Disable 1: Enable
[4]	AMP0M_GND	Enable the negative input of AMP0, after which the built-in P3.0 pin is wired to GND 0: Disable 1: Enable
[3]	AMP3EN	AMP3 Enable 0: Disable 1: Enable
[2]	AMP2EN	AMP2 Enable 0: Disable 1: Enable
[1]	AMP1EN	AMP1 Enable 0: Disable 1: Enable
[0]	AMP0EN	AMP0 Enable 0: Disable 1: Enable

### 28.3.2 AMP\_CR1 (0x4034)

Bit	7	6	5	4	3	2	1	0
Name	AMP_PH_GAIN			RSV		AMP0_GAIN		
Type	R/W	R/W	R/W	-	-	R/W	R/W	R/W
Reset	0	0	0	-	-	0	0	0

Bit	Name	Description
[7:5]	AMP_PH_GAIN	Gain setting for AMP1&AMP2, see descriptions on AMP_CR1[AMP0_GAIN] bit in section AMP_CR1 (0x4034).
[4:3]	RSV	Reserved
[2:0]	AMP0_GAIN	Amplification Gain Setting 000: The gain is configured by external circuit 001: 2x 010: 4x 011: 8x 100: 16x 101: Reserved 110: Reserved 111: Reserved Note: The built-in amplification is isotropic amplification. When the difference of input voltage is 0, the output voltage is VHALF. For other applications, AMP0_GAIN is set to "000" to select external circuit to configure the gain.

**28.3.3 AMP\_CR2 (0x4046)**

Bit	7	6	5	4	3	2	1	0
Name	RSV					AMP3_GAIN		
Type	-	-	-	-	-	R/W	R/W	R/W
Reset	-	-	-	-	-	0	0	0
Bit	Name	Description						
[7:3]	RSV	Reserved						
[2:0]	AMP3_GAIN	Amplification gain for AMP3. See descriptions on AMP_CR1[AMP0_GAIN] bit in section AMP_CR1 (0x4034).						

## 29 Comparator

### 29.1 Comparator Operations

#### 29.1.1 Comparator CMP3

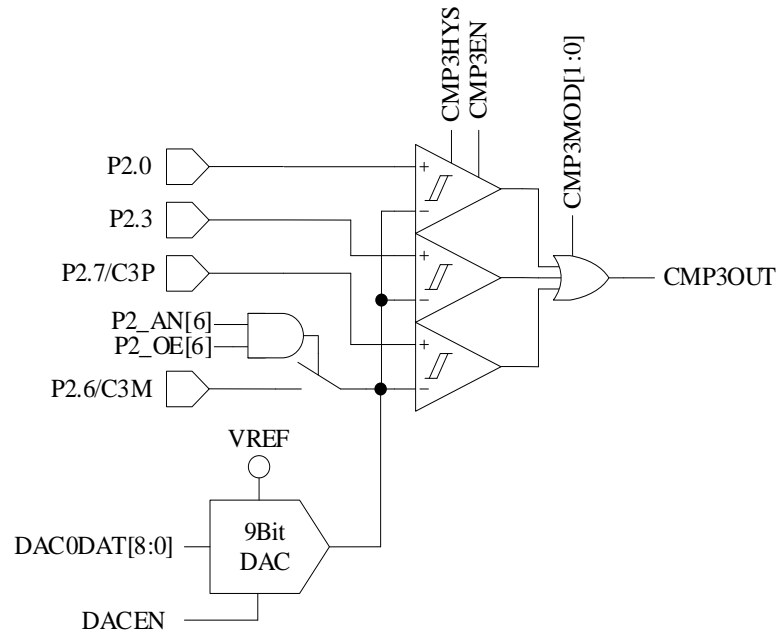


Figure 29-1 CMP3 I/O Pins

The I/O pins of CMP3 are shown in Figure 29-1. CMP3 configurations are as follows:

1. Configure P2\_AN[6] and P2\_OE[6] to “1” to enable VREF on the negative input of CMP3. The VREF source can be on-chip DAC0 output voltage or external circuit input voltage. Select DAC0 output, and place an external capacitor between P2.6 pin and GND (the recommended capacitance value is 100pF, and the output voltage stabilizes after DAC0 output for a period of time);
2. Configure CMP\_CR1[CMP3MOD] to select single-comparator input, dual-comparator input, or triple-comparator input mode;
  - When CMP\_CR1[CMP3MOD] = 00, CMP3 works in Single-comparator Input Mode. The connection of input and output pins are shown in Figure 29-2.
  - When CMP\_CR1[CMP3MOD] = 01, CMP3 works in Dual-comparator Input Mode. The connection of input and output pins are shown in Figure 29-3.
  - When CMP\_CR1[CMP3MOD] = 1X, CMP3 works in Triple-comparator Input Mode. The connection of input and output pins are as shown in Figure 29-4.
3. Configure CMP\_CR1[CMP3HYS] to enable or disable hysteresis;
4. Set CMP\_CR1[CMP3EN] = 1 to enable CMP3.

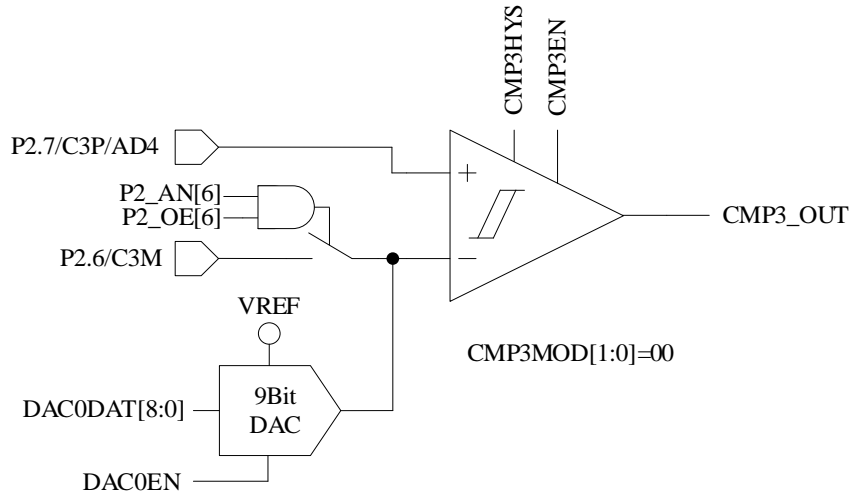


Figure 29-2 Single-comparator Input Mode

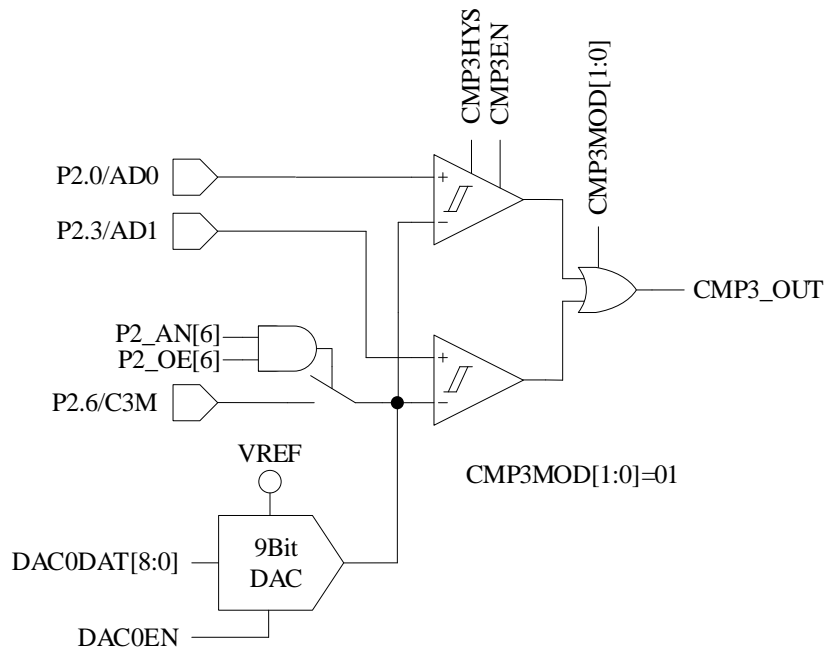


Figure 29-3 Dual-comparator Input Mode

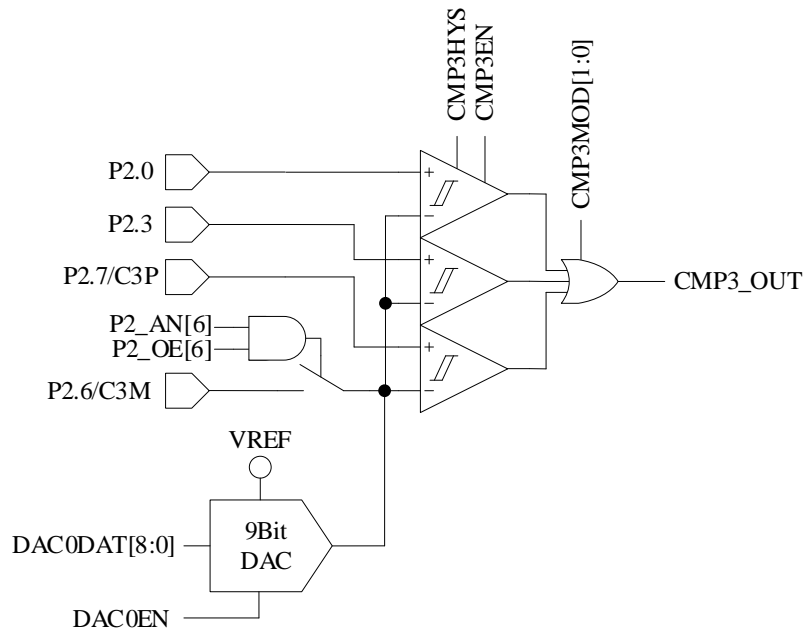


Figure 29-4 Triple-comparator Input Mode

### 29.1.1.1 Over-current Protection (OCP)

When an over-current protection signal is generated, DRV\_OUT[MOE] is automatically cleared to output idle voltage to stop motor drive for chip and motor protection. OCP feature is enabled when EVT\_FILT[MOEMD] = 01, which automatically turns off the output and generates an OCP interrupt request if the current exceeds the threshold. When EVT\_FILT[MOEMD]=00, the output is not automatically turned off if the current exceeds the threshold. However, an OCP request is generated by the hardware.

The source of OCP interrupt is selected by configuring EVT\_FILT[MOEMD]  $\neq$  00 and EVT\_FILT[INT0\_MOE\_EN] = 1, namely CMP3 interrupt or external interrupt INT0. When EVT\_FILT[INT0\_MOE\_EN]=1, TCON[IT0] bit is programmed to select the trigger edge of the external interrupt INT0 which generates an OCP output. At this time, the source of OCP interrupt is INT0. When EVT\_FILT[INT0\_MOE\_EN] = 0 and CMP\_CR0[CMP3IM] = 11, the OCP output is generated on the raising edge of CMP3. At this time, the source of OCP interrupt is CMP3. In triple-shunt current sampling mode, CMP\_CR1[CMP3MOD] is configured to select triple-comparator input mode. When current of any phase is over the threshold, CMP3 generates an OCP signal. For other sampling modes, CMP\_CR1[CMP3MOD] is configured to choose single-comparator input mode. When bus current is over the threshold, CMP3 generates an OCP signal.

Configuring EVT\_FILT[EFDIV] enables the filtering of interrupt signals for OCP, and programming EVT\_FILT[EFDIV] = 01/10/11 selects filter width of 6/12/24 clock cycles. When the filtering feature is enabled, the filtered signal is delayed by 6/12/24 clock cycles compared to the signal before filtering.

### 29.1.1.2 Cycle-by-cycle Current Limiting

The cycle-by-cycle current limiting feature is applied to square-wave-based drive control of BLDC motors. When an OCP event occurs, DRV\_OUT[MOE] is set to “1” after it has been cleared to “0” for a period of time, so that the motor drive is automatically restored. When CMP\_CR0[**CMP3IM**] = 11, DRV\_OUT[MOE] is cleared to “0” on the rising edge of CMP3OUT to protect the motor. When EVT\_FILT[**MOEMD**] = 10, the outputs are automatically turned off upon an OCP interrupt. DRV\_OUT[MOE] is enabled automatically upon Driver timer overflow/underflow events or after 10 $\mu$ s to restore motor drive. When EVT\_FILT[**MOEMD**] = 11, the outputs are automatically turned off upon an OCP interrupt, DRV\_OUT[MOE] is enabled automatically upon Driver timer overflow/underflow events or after 5 $\mu$ s to restore motor drive.

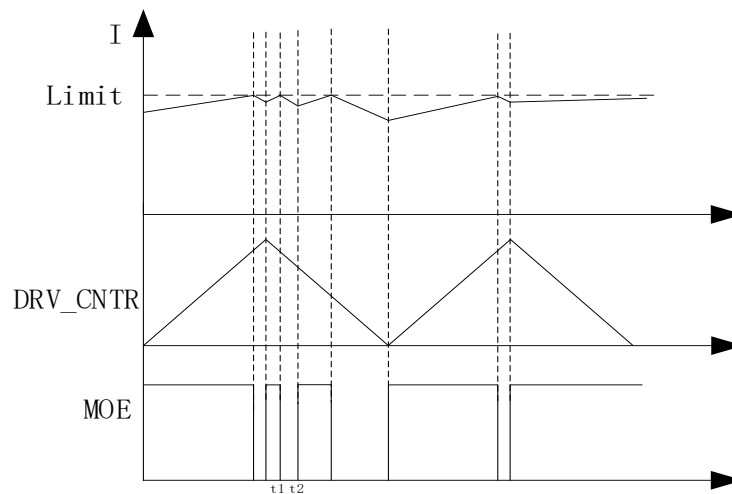


Figure 29-5 Cycle-by-cycle Current Limiting Waveform ( $t_2 - t_1 = 10\mu\text{s}$ ) when EVT\_FILT[MOEMD] = 10

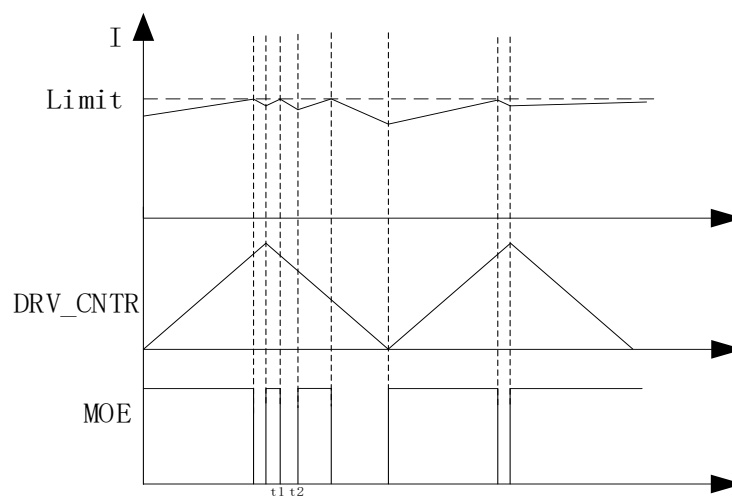


Figure 29-6 Cycle-by-cycle Current Limiting Waveform ( $t_2 - t_1 = 5\mu\text{s}$ ) when EVT\_FILT[MOEMD] = 11

### 29.1.2 Comparator CMP4

CMP4 is a hysteresis comparator, as shown in Figure 29-7. CMP4OUT can be read by software or reversed on external interrupt INT0. When CMP3 is used for cycle-by-cycle current limiting protection, CMP4 is used for bus current protection. When bus current OCP feature of CMP4 is triggered, output must be turned off by software.

CMP4 configurations are as follows:

1. Configure P2\_AN[3] and P2\_OE[3] to “1” to enable VREF on the positive input of CMP4. The VREF source can be on-chip DAC1 output voltage or external circuit input voltage. Select DAC1 output, and place an external capacitor between P2.3 pin and GND (the recommended capacitance value is 100pF, and the output voltage stabilizes after DAC1 output for a period of time);
2. Configure P2\_AN[7] = 1 to assign P2.7 pin to analog signal;
3. Configure CMP\_CR2[CMP4EN] = 1 to enable CMP4;
4. Clear INT0 flag bit to enable INT0;
5. Set LVSR[EXT0CFG] = 111 to select CMP4 as the source of INT0;
6. Configure TCON[IT0] = 01 to select falling edge triggered INT0;

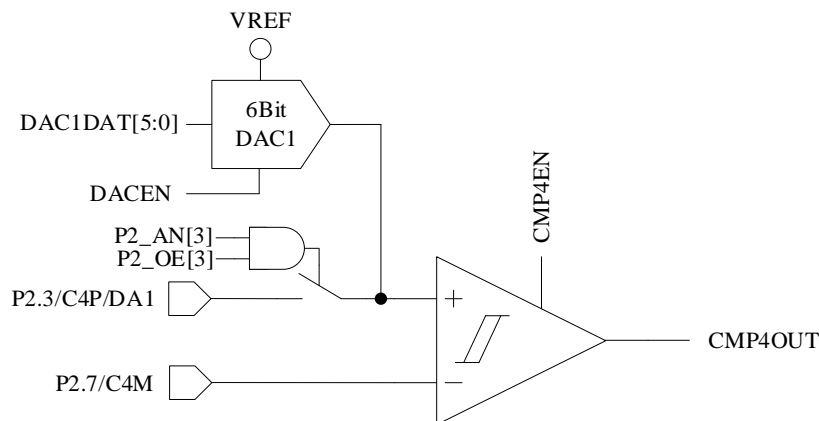


Figure 29-7 Schematic Diagram of CMP4 Module

### 29.1.3 Comparator CMP5

CMP5 is a hysteresis comparator, as shown in Figure 29-8. CMP5OUT can be read by software. When CMP5 is used for cycle-by-cycle current limiting protection, PFC module is used for cycle-by-cycle current limiting or current protection.

CMP5 configurations are as follows:

1. Configure P1\_AN[3] = 1 and P1\_AN[5] = 1 to assign P1.3/C5P and P1.5/C5M pins to analog signal;
2. Configure CMP\_CR4[CMP5EN] = 1 to enable CMP5.

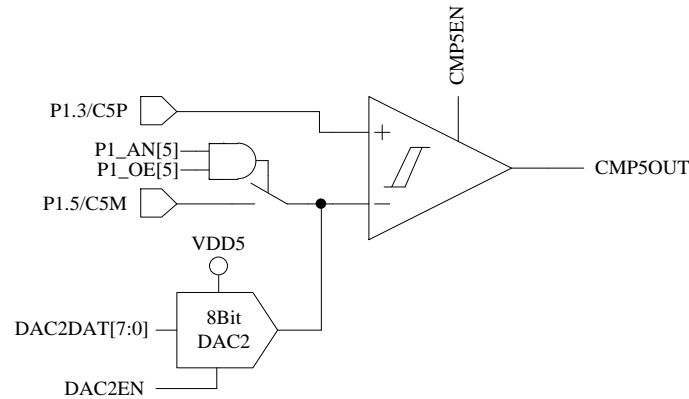


Figure 29-8 Schematic Diagram of CMP5 Module

### 29.1.4 Comparator Group (CMPG)

Comparator Group (CMPG) is a collection of CMP0, CMP1 and CMP2, with multiple comparison modes for different applications.

When  $CMP\_CR2[CMP0MOD] = 00$ , CMPG works in the mode of three comparators without built-in resistor. The I/O pins are shown in Figure 29-9. It is used for BEMF detection with the external virtual neutral point resistors. The negative inputs of the three comparators are connected together to P1.5 pin, and the positive inputs are connected to P1.4, P1.6 and P2.1 respectively. The outputs are CMP0OUT, CMP1OUT and CMP2OUT respectively. The number of comparators working in this mode is defined by  $CMP\_CR2[CMP0SEL]$ . When  $CMP\_CR2[CMP0SEL] = 00$ , CMP0, CMP1 and CMP2 work simultaneously, which is the recommended configuration. When  $CMP\_CR2[CMP0SEL] = 01$ , only CMP0 works. When  $CMP\_CR2[CMP0SEL] = 10$ , only CMP1 works. When  $CMP\_CR2[CMP0SEL] = 11$ , only CMP2 works.

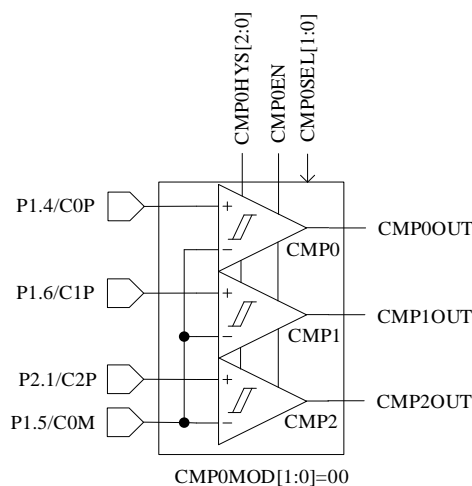


Figure 29-9 CMPG Mode with Built-in Three Comparators

(without Built-in Resistor)



When  $CMP\_CR2[CMP0MOD] = 01$ , CMPG works in the mode of three comparators with built-in resistors. It is used for BEMF detection with the internal virtual neutral point resistors. The input port is selected by setting the function switching bit  $CMP\_CR4[CMP0FS]$ . The number of comparators operating in this mode is defined by  $CMP\_CR2[CMP0SEL]$ . When  $CMP\_CR2[CMP0SEL] = 00$ , CMP0, CMP1 and CMP2 work simultaneously, which is the recommended configuration. When  $CMP\_CR2[CMP0SEL] = 01$ , only CMP0 works. When  $CMP\_CR2[CMP0SEL] = 10$ , only CMP1 works. When  $CMP\_CR2[CMP0SEL] = 11$ , only CMP2 works.

When  $CMP\_CR4[CMP0FS] = 0$ , the I/O pins are shown in Figure 29-10. The negative inputs of the three comparators are connected together to the center point of the built-in resistor. The positive inputs are connected to P1.4, P1.6 and P2.1 respectively, and the outputs are CMP0OUT, CMP1OUT and CMP2OUT respectively.

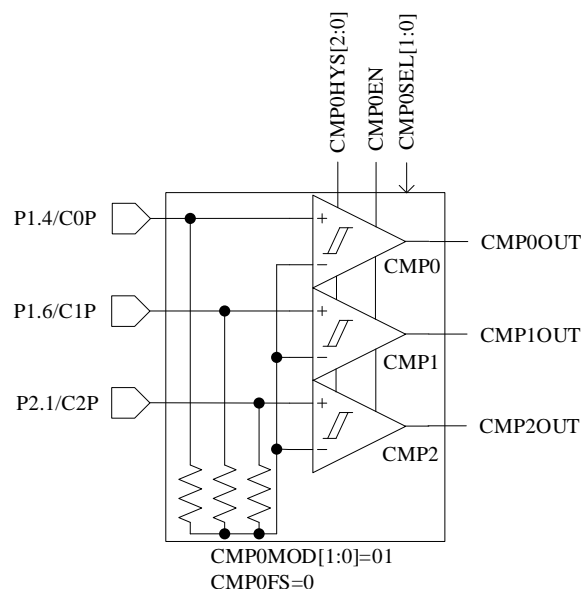


Figure 29-10 CMPG Mode with Built-in Three Comparators and Resistors

(without Functional Switching)

When  $CMP\_CR4[CMP0FS] = 1$ , the I/O pins are shown in Figure 29-11. The negative inputs of the three comparators are connected together to the center point of the built-in resistor. The positive inputs are connected to P1.4, P1.3 and P1.5 respectively, and the outputs are CMP0OUT, CMP1OUT and CMP2OUT respectively.

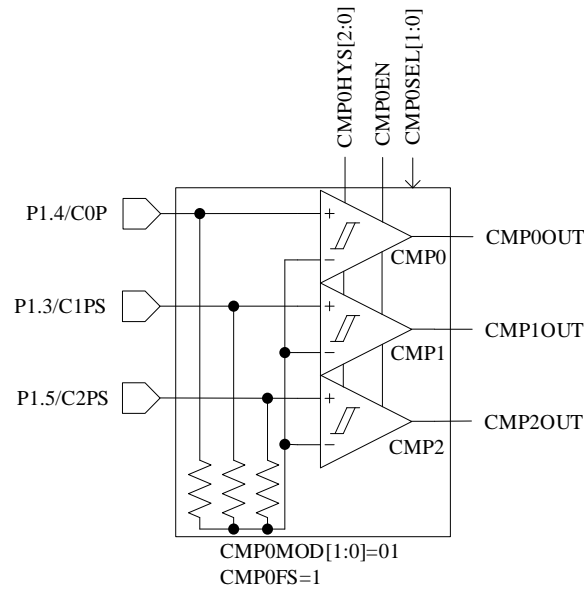


Figure 29-11 CMPG Mode with Built-in Three Comparators (with Functional Switching)

When  $CMP\_CR2[CMP0MOD] = 10$ , CMPG mode with three differential comparators is selected for the differential Hall sensor to detect the motor rotor position. The input and output pins are shown in Figure 29-12. The negative inputs of the three comparators are respectively connected to P1.5, P1.7 and P2.2, and the positive inputs are respectively connected to P1.4, P1.6 and P2.1. The outputs are CMP0OUT, CMP1OUT and CMP2OUT respectively. The number of comparators working in this mode is defined by  $CMP\_CR2[CMP0SEL]$ . When  $CMP\_CR2[CMP0SEL] = 00$ , CMP0, CMP1 and CMP2 work simultaneously, which is the recommended configuration. When  $CMP\_CR2[CMP0SEL] = 01$ , only CMP0 works. When  $CMP\_CR2[CMP0SEL] = 10$ , only CMP1 works. When  $CMP\_CR2[CMP0SEL] = 11$ , only CMP2 works.

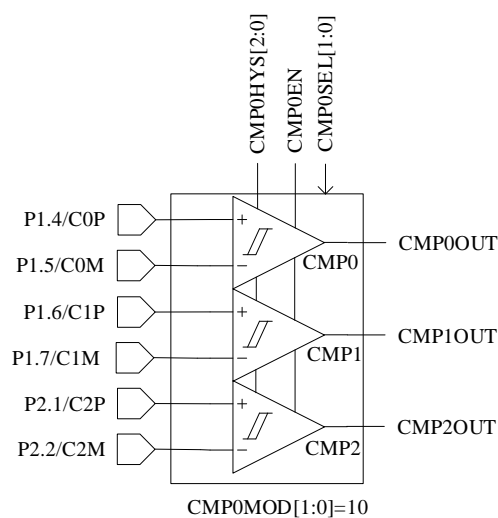


Figure 29-12 CMPG Mode with Three Differential Comparators

When  $CMP\_CR2[CMP0MOD] = 11$ , CMPG mode with two comparators is selected for motor speed detection. The I/O pins are shown in Figure 29-13. The negative inputs of the two comparators are connected together to P1.5, and the positive inputs are connected to P1.4 and P1.3 respectively. The outputs are CMP0OUT and CMP1OUT respectively. The number of comparators in this mode is defined by  $CMP\_CR2[CMP0SEL]$ . When  $CMP\_CR2[CMP0SEL] = 00$ , CMP0 and CMP1 work simultaneously, which is the recommended configuration. When  $CMP\_CR2[CMP0SEL] = 01$ , only CMP0 works. When  $CMP\_CR2[CMP0SEL] = 10$ , only CMP1 works.

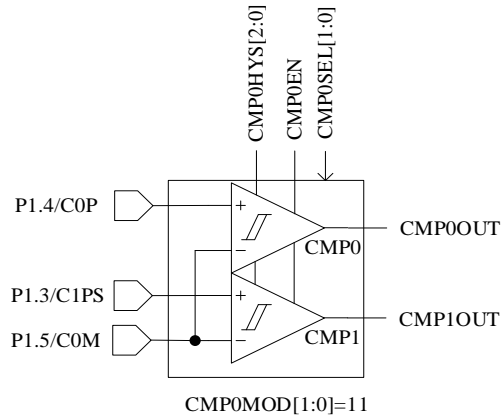


Figure 29-13 CMPG Mode with Two Comparators

The output signals of CMP0/CMP1/CMP2 are sent to Timer1 after filtering and sampling modules.

### 29.1.5 Comparator Sampling

The comparator sampling feature is mainly used for the square-wave control and RSD (tailwind/headwind detection), which eliminates the switching interference from driving circuit. See section 14.1.2.3 for square-wave control and section 15.1.7.1 for RSD.

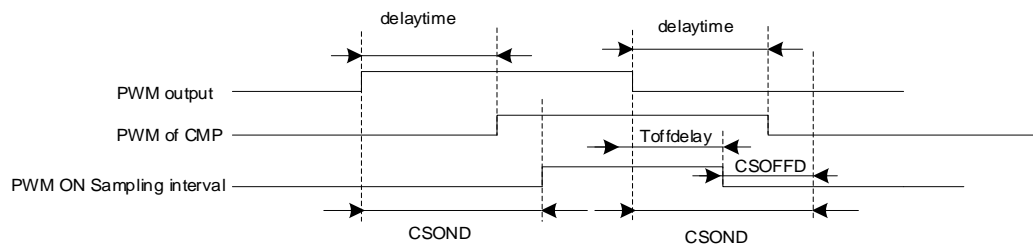


Figure 29-14 PWM ON Sampling Mode

There is a delay from the PWM output to the output of the comparator, which is mainly affected by the following factors: resistance value of drive resistor, switching speed of the power device, and input delay and hysteresis settings of the comparator. As shown in Figure 29-14, the delay-time is from the chip output to the

comparator output. When high-level sampling is performed, the sampling interval shall be enveloped by actual high-level output of the comparator. First, the sampling ON-delayed time  $CMP\_SAMR[CSOND]$  is set to overcome the output delay and the oscillation interval of the power device. At the end of the sampling interval,  $CMP\_SAMR[CSOND]$  is delayed after the falling edge of PWM, at which time the actual sampling window has exceeded the corresponding high-level interval. The sampling OFF-lead time  $CMP\_SAMR[CSOFFD]$  is set to stop sampling  $Toffdelay$  after the PWM output falling edge, where  $Toffdelay = CMP\_SAMR[CSOND] - CMP\_SAMR[CSOFFD]$ . By configuring  $CMP\_SAMR[CSOND]$  and  $CMP\_SAMR[CSOFFD]$ , the sampling interval can be located in the high-level interval of the actual output of the comparator.

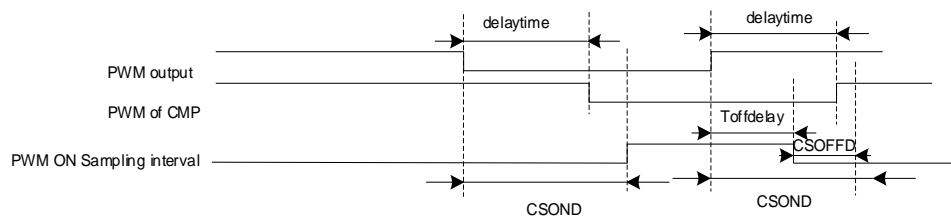


Figure 29-15 PWM OFF Sampling Mode

Similarly, when low-level sampling is performed, the sampling ON-delayed time  $CMP\_SAMR[CSOND]$  and the sampling OFF-lead time  $CMP\_SAMR[CSOFFD]$  are set reasonably to ensure that the actual sampling interval is located in the low-level output interval of the comparator.

Method for measuring the delay of PWM output to comparator: Set  $CMP\_CR3[SAMSEL] = 00$  to disable the comparator sampling delay feature. Set  $CMP\_CR3[CMPSSEL]$  to select the corresponding comparator output to test pin P0.7 (FU6815L). Enable the PWM output and comparator, manually rotate the motor to change the comparator value, and measure the delay between the PWM output and the comparator output.

### 29.1.6 Comparator Output

$CMP\_CR3[CMPSSEL]$  is configured to output results of one comparator to P0.7 or select function switching to P0.1.

## 29.2 Comparator Registers

### 29.2.1 CMP\_CR0 (0xD5)

Bit	7	6	5	4	3	2	1	0
Name	CMP3IM		CMP2IM		CMP1IM		CMP0IM	
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:6]	CMP3IM	CMP3 Interrupt Mode 00: No interrupt is generated. 01: An interrupt is generated upon rising edge. 10: An interrupt is generated upon falling edge. 11: When a rising edge is detected, DRV_OUT[MOE] is cleared to “0”, and the interrupt event flag bit CMP_SR[CMP3IF] is set to “1”. However, the interrupt is disabled. (Note: In the Cycle-by-cycle Current Limiting mode, EVT_FILT[MOEMD] must be set to 10/11).						
[5:4]	CMP2IM	CMP2 Interrupt Mode See descriptions on CMP_CR0[CMP0IM].						
[3:2]	CMP1IM	CMP1 Interrupt Mode See descriptions on CMP_CR0[CMP0IM]						
[1:0]	CMP0IM	CMP0 Interrupt Mode 00: No interrupt is generated. 01: An interrupt is generated upon rising edge. 10: An interrupt is generated upon falling edge. 11: An interrupt is generated upon both rising/falling edges.						

### 29.2.2 CMP\_CR1 (0xD6)

Bit	7	6	5	4	3	2	1	0
Name	RSV	CMP3MOD		CMP3EN	CMP3HYS	CMP0HYS		
Type	-	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	RSV	Reserved						
[6:5]	CMP3MOD	CMP Mode Selection Negative input is connected to P2.6 or DAC0 output 00: Single-comparator mode, where P2.7 is connected to the positive input, as shown in Figure 29-2. 01: Dual-comparator mode, where P2.0 and P2.3 are connected to the positive input, as shown in Figure 29-3. 1X: Three-comparator mode, where P2.0, P2.3 and P2.7 are connected to the positive input, as shown in Figure 29-4.						
[4]	CMP3EN	CMP3 Enable 0: Disable 1: Enable						
[3]	CMP3HYS	CMP3 Hysteresis Voltage Selection 0: No hysteresis 1: Hysteresis voltage is selected						
[2:0]	CMP0HYS	CMP0/1/2 Hysteresis Voltage Selection: 000: No hysteresis 001: ±3mV 010: -6mV 100: +6mV 011: ±6mV						

		101: -12mV 110: +12mV 111: ±12mV
--	--	--

**29.2.3 CMP\_CR2 (0xDA)**

Bit	7	6	5	4	3	2	1	0
Name	CMP4EN	CMP0MOD		CMP0SEL		RSV		CMP0EN
Type	R/W	R/W	R/W	R/W	R/W	-	-	R/W
Reset	0	0	0	0	0	-	-	0

Bit	Name	Description															
[7]	CMP4EN	CMP4 Enable 0: Disable 1: Enable															
[6:5]	CMP0MOD	CMPG Mode Setting 00: CMPG Mode with built-in three comparators (without built-in resistor), as shown in Figure 29-9. 01: CMPG Mode with built-in three comparators and resistors, where function switching is selected by configuring CMP_CR4[CMP0FS], as shown in Figure 29-10 and Figure 29-11. 10: CMPG Mode with three differential comparators, as shown in Figure 29-12. 11: CMPG Mode with two comparators, where only CMP0 and CMP1 work, as shown in Figure 29-13.															
[4:3]	CMP0SEL	<p>CMPG Pin Combination Selection, used with CMP_CR2[CMP0MOD] bit. It is set to 00 by default. In square-wave drive application, TIM1_DBRx[T1CPE] automatically controls CMP_CR2[CMP0SEL] to enable or disable each comparator.</p> <p>Table 29-1 Function Description of CMPG Port and CMP_CR2[CMP0MOD] Combination</p> <table border="1"> <thead> <tr> <th>CMP0MOD</th> <th>CMP0SEL</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td rowspan="4">00</td> <td>00</td> <td>CMP0/1/2 work simultaneously, as shown in Figure 29-9. The negative input of these comparators are connected to COM. The hardware automatically compares the positive inputs C0P, C1P and C2P with C0M, and the output results are transferred to CMP0OUT, CMP1OUT and CMP2OUT respectively.</td> </tr> <tr> <td>01</td> <td>Only CMP0 works. The positive input is connected to C0P, and the negative input to C0M. The output results are transferred to CMP0OUT.</td> </tr> <tr> <td>10</td> <td>Only CMP1 works. The positive input is connected to C1P, and the negative input to C0M. The output results are transferred to CMP1OUT.</td> </tr> <tr> <td>11</td> <td>Only CMP2 works. The positive input is connected to C2P, and the negative input to C0M. The output results are transferred to CMP2OUT.</td> </tr> <tr> <td>01</td> <td>00</td> <td>CMP0/1/2 work simultaneously, as shown in Figure 29-10 and Figure 29-11. The negative inputs of these 3 comparators are connected to the center of built-in resistor. When CMP_CR4[CMP0FS] = 0, the hardware automatically compares the positive inputs C0P, C1P and C2P with C0M. When CMP_CR4[CMP0FS] = 1, the hardware automatically compares the positive inputs C0P, C1PS and C2PS with C0M. The output results are transferred to CMP0OUT, CMP1OUT and CMP2OUT respectively.</td> </tr> </tbody> </table>	CMP0MOD	CMP0SEL	Description	00	00	CMP0/1/2 work simultaneously, as shown in Figure 29-9. The negative input of these comparators are connected to COM. The hardware automatically compares the positive inputs C0P, C1P and C2P with C0M, and the output results are transferred to CMP0OUT, CMP1OUT and CMP2OUT respectively.	01	Only CMP0 works. The positive input is connected to C0P, and the negative input to C0M. The output results are transferred to CMP0OUT.	10	Only CMP1 works. The positive input is connected to C1P, and the negative input to C0M. The output results are transferred to CMP1OUT.	11	Only CMP2 works. The positive input is connected to C2P, and the negative input to C0M. The output results are transferred to CMP2OUT.	01	00	CMP0/1/2 work simultaneously, as shown in Figure 29-10 and Figure 29-11. The negative inputs of these 3 comparators are connected to the center of built-in resistor. When CMP_CR4[CMP0FS] = 0, the hardware automatically compares the positive inputs C0P, C1P and C2P with C0M. When CMP_CR4[CMP0FS] = 1, the hardware automatically compares the positive inputs C0P, C1PS and C2PS with C0M. The output results are transferred to CMP0OUT, CMP1OUT and CMP2OUT respectively.
CMP0MOD	CMP0SEL	Description															
00	00	CMP0/1/2 work simultaneously, as shown in Figure 29-9. The negative input of these comparators are connected to COM. The hardware automatically compares the positive inputs C0P, C1P and C2P with C0M, and the output results are transferred to CMP0OUT, CMP1OUT and CMP2OUT respectively.															
	01	Only CMP0 works. The positive input is connected to C0P, and the negative input to C0M. The output results are transferred to CMP0OUT.															
	10	Only CMP1 works. The positive input is connected to C1P, and the negative input to C0M. The output results are transferred to CMP1OUT.															
	11	Only CMP2 works. The positive input is connected to C2P, and the negative input to C0M. The output results are transferred to CMP2OUT.															
01	00	CMP0/1/2 work simultaneously, as shown in Figure 29-10 and Figure 29-11. The negative inputs of these 3 comparators are connected to the center of built-in resistor. When CMP_CR4[CMP0FS] = 0, the hardware automatically compares the positive inputs C0P, C1P and C2P with C0M. When CMP_CR4[CMP0FS] = 1, the hardware automatically compares the positive inputs C0P, C1PS and C2PS with C0M. The output results are transferred to CMP0OUT, CMP1OUT and CMP2OUT respectively.															

			01	Only CMP0 works. The positive input is connected to C0P, and the negative input to the center of BEMF built-in resistor. The output results are transferred to CMP0OUT.
			10	Only CMP1 works. When CMP_CR4[CMP0FS] = 0, the positive input is connected to C1P, and when CMP_CR4[CMP0FS] = 1, it is connected to C1PS. The negative input is connected to the center of BEMF built-in resistor. The output results are transferred to CMP1OUT.
			11	Only CMP2 works. When CMP_CR4[CMP0FS] = 0, the positive input is connected to C2P, and when CMP_CR4[CMP0FS] = 1, it is connected to C2PS. The negative input is connected to the center of BEMF built-in resistor. The output results are transferred to CMP2OUT.
		10	00	CMP0/1/2 work simultaneously, as shown in Figure 29-12. The positive inputs of these comparators are connected to C0P, C1P and C2P respectively, and the negative inputs are connected to C0M, C1M and C2M respectively. The output results are transferred to CMP0OUT, CMP1OUT and CMP2OUT respectively.
			01	Only CMP0 works. The positive input is connected to C0P, and the negative input to C0M, and the output results are transferred to CMP0OUT.
			10	Only CMP1 works. The positive input is connected to C1P, and the negative input to C1M. The output results are transferred to CMP1OUT.
			11	CMPG selects the associated CMP2 pin combinations. The positive input is connected to C2P, and the negative input to C2M. The output results are transferred to CMP2OUT.
		11	00	CMP0/1 work simultaneously, as shown in Figure 29-13. The positive inputs are connected to C0P and C1PS respectively, and the negative inputs to C0M. The outputs results are transferred to CMP0OUT and CMP1OUT respectively.
			01	Only CMP0 works. The positive input is connected to C0P, and the negative input to C0M. The output results are transferred to CMP0OUT.
			10	Only CMP1 works. The positive input is connected to C1PS, and the negative input to C0M. The output results are transferred to CMP1OUT.
			11	Reserved
[2:1]	RSV	Reserved		
[0]	CMP0EN	CMP0 Enable 0: Disable 1: Enable		

**29.2.4 CMP\_CR3 (0xDC)**

Bit	7	6	5	4	3	2	1	0
Name	CMPDTEN	DBGSEL		SAMSEL		CMPSEL		
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	CMPDTEN	Comparator Deadtime Sampling Enable 0: Disable 1: Enable						
[6:5]	DBGSEL	Debug Output Selection, connected to P0.1 pin 00: Debug Output Disable 01: Freewheeling shielding is completed and ZCP signal is detected 10: ADC Trigger Signal 11: Comparator Sampling Interval						
[4:3]	SAMSEL	Sampling delay enable of CMP0, CMP1, CMP2 and ADC in PWM ON/OFF modes 00: Sampling at both PWM ON and OFF modes without time delay 01: Sampling at PWM OFF mode, with time delay according to CMP_SAMR 10: Sampling at PWM ON mode, with time delay according to CMP_SAMR 11: Sampling at both PWM ON and OFF, with time delay according to CMP_SAMR						
[2:0]	CMPSEL	Comparator Output Selection Output signals of one selected comparator to P0.7, which can be switched to P0.1. 000: No output 001: CMP0 010: CMP1 011: CMP2 100: CMP3 101: CMP4 110: CMP5 111: Omega Start Flag (Estimator Output Angle Flag, see section 13.1.8.7 for details)						

**29.2.5 CMP\_CR4 (0xE1)**

Bit	7	6	5	4	3	2	1	0
Name	CMP4OUT	CMP5OUT	RSV	CMP3P4M_FS	CMP5_HYS	FAEN	CMP0FS	CMP5EN
Type	R	R	-	R/W	R/W	R/W	R/W	-
Reset	1	0	-	0	0	0	0	-
Bit	Name	Description						
[7]	CMP4OUT	CMP4 Output						
[6]	CMP5OUT	CMP5 Output						
[5]	RSV	Reserved						
[4]	CMP3P4M_FS	CMP3P and CMP4M are switched to output at P3.4. It is used to directly transfer the sampled bus current (bus current operational amplifier AMP00 output to P3.4) to OCP comparator. 0: No function switching. 1: Function switching to output at P3.4 pin, where CMP3 has only one input channel at the positive input.						
[3]	CMP5_HYS	Hysteresis Configuration of Comparator 5 0: Without hysteresis 1: With hysteresis						



[2]	FAEN	Filtered Signal Sampling Coefficient Scale-up Enable With it enabled, base clock rates of TIM1_CR3[T1INM] and CMP_SAMR are scaled up by 4 times. 0: Disable 1: Enable
[1]	CMP0FS	CMP1/CMP2 Function Switching 0: No function switching, as shown in Figure 29-10 1: Function switching, valid only when CMP_CR2[CMP0_MOD] = 01, as shown in Figure 29-11.
[0]	CMP5EN	Comparator 5 Enable 0: Disable 1: Enable

### 29.2.6 CMP\_SAMR (0x40AD)

Bit	7	6	5	4	3	2	1	0
Name	CSOND				CSOFFD			
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	1
Bit	Name	Description						
[7:4]	CSOND	<p>CMP0/CMP1/CMP2 ON-delayed Sampling Time</p> <p>When PWM module switches from OFF to ON or from ON to OFF, turn-on/off of the power device affects input signal of the comparator. In this case, CMP_SAMR[CSOND] is configured to delay the sampling of CMP0/CMP1/CMP2. The On-delayed sampling time can be multiplied by 4 times by setting CMP_CR4[FAEN].</p> <p>CMP_CR4[FAEN] = 0: ON-delayed sampling time = <math>8 * \text{CMP\_SAMR[CSOND]} * T</math>            CMP_CR4[FAEN] = 1: ON-delayed sampling time = <math>32 * \text{CMP\_SAMR[CSOND]} * T</math></p> <p>Notes:</p> <ul style="list-style-type: none"> <li>■ CMP_SAMR[CSOND] must be greater than or equal to CMP_SAMR[CSOFFD].</li> <li>■ See section Sampling for BLDC drive application.</li> <li>■ See section RSD Comparator Sampling for RSD application.</li> </ul>						
[3:0]	CSOFFD	<p>CMP0/CMP1/CMP2 OFF-lead Sampling Time</p> <p>CMP_SAMR[CSOND] is configured to end the sampling CMP_SAMR[CSOND] - CMP_SAMR[CSOFFD] after the back edge of PWM output to ensure sampling interval is enveloped by the PWM interval. OFF-lead sampling time can be multiplied by 4 times by setting CMP_CR4[FAEN].</p> <p>CMP_CR4[FAEN] = 0: OFF-lead sampling time = <math>8 * \text{CMP\_SAMR[CSOFFD]} * T</math>            CMP_CR4[FAEN] = 1: OFF-lead sampling time = <math>32 * \text{CMP\_SAMR[CSOFFD]} * T</math></p> <p>Notes:</p> <ul style="list-style-type: none"> <li>■ CMP_SAMR[CSOND] must be greater than or equal to CMP_SAMR[CSOFFD].</li> <li>■ See section Sampling for BLDC drive application.</li> <li>■ See section RSD Comparator Sampling for RSD application.</li> </ul>						

**29.2.7 CMP\_SR (0xD7)**

Bit	7	6	5	4	3	2	1	0
Name	CMP3IF	CMP2IF	CMP1IF	CMP0IF	CMP3OUT	CMP2OUT	CMP1OUT	CMP0OUT
Type	R/W0	R/W0	R/W0	R/W0	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	CMP3IF	CMP3 Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect						
[6]	CMP2IF	CMP2 Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect						
[5]	CMP1IF	CMP1 Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect						
[4]	CMP0IF	CMP0 Interrupt Flag: Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect						
[3]	CMP3OUT	CMP3 comparison result						
[2]	CMP2OUT	CMP2 comparison result						
[1]	CMP1OUT	CMP1 comparison result						
[0]	CMP0OUT	CMP0 comparison result						

**29.2.8 HALL\_CR (0xE2)**

Bit	7	6	5	4	3	2	1	0
Name	HALL_IF	HALL_IE	RSV		HALLSEL	HALL2	HALL1	HALL0
Type	R/W	R/W	-	-	R/W	R/W	R/W	R/W
Reset	0	0	-	-	0	0	0	0
Bit	Name	Description						
[7]	HALL_IF	Hall Interrupt Flag 0: No Hall edge change is detected. 1: Hall edge change is detected.						
[6]	HALL_IE	Hall Interrupt Enable 0: Disable 1: Enable						
[5:4]	RSV	Reserved						

[3]	HALLSEL	Hall Input Selection 0:P0.2/P3.6/P3.7 1:P1.4/P1.6/P2.1
[2]	HALL2	Hall2 Level 0: Hall2 level = 0 1: Hall2 level = 1
[1]	HALL1	Hall1 Level 0: Hall1 level = 0 1: Hall1 level = 1
[0]	HALL0	Hall0 Level 0: Hall0 level = 0 1: Hall0 level = 1

### 29.2.9 EVT\_FILT (0xD9)

Bit	7	6	5	4	3	2	1	0
Name	RSV			MOEMD		INT0_MOE_EN	EFDIV	
Type	-	-	-	R/W	R/W	R/W	R/W	R/W
Reset	-	-	-	0	0	0	0	0
Bit	Name	Description						
[7:5]	RSV	Reserved						
[4:3]	MOEMD	MOE Cleared and Enabled by Hardware MOE is cleared and enabled by hardware upon over-/under-current protection event. 00: MOE is not automatically cleared. 01: MOE is automatically cleared. 10: MOE is automatically cleared and enabled by hardware upon Driver timer overflow/underflow events or after 10 $\mu$ s (for square-wave drive). 11: MOE is automatically cleared and enabled automatically upon Driver timer overflow/underflow events or after 5 $\mu$ s (for square-wave drive).						
[2]	INT0_MOE_EN	MOE OFF triggered by INT0 Interrupt 0: Disable 1: Enable						
[1:0]	EFDIV	Filter Width for Current Protection 00: Not to filter 01: 6 system clock cycles 10: 12 system clock cycles 11: 24 system clock cycles						

### 29.2.10 TSD\_CR (0x402F)

Bit	7	6	5	4	3	2	1	0
Name	TSDEN	RSV			TSDADJ			
Type	R/W	-	-	-	R/W	R/W	R/W	R/W
Reset	0	-	-	-	0	1	1	0
Bit	Name	Description						
[7]	TSDEN	Temperature Detection Feature Enable 0: Disable 1: Enable						
[6:4]	RSV	Reserved						
[3:0]	TSDADJ	Overtemperature Value (Chip Junction Temperature) 0000: 65°C 0001: 70°C 0010: 75°C 0011: 80°C 0100: 86°C						

		0101: 91°C 0110: 97°C 0111: 103°C 1000: 109°C 1001: 115°C 1010: 121°C 1011: 128°C 1100: 135°C 1101: 142°C 1110: 150°C 1111: Reserved
--	--	--

## 30 Power Supply

### 30.1 LDO Operations

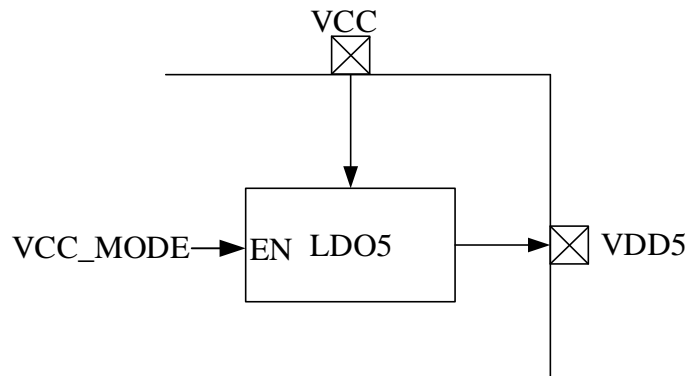


Figure 30-1 Functional Block Diagram of Power Supply

The I/O pins of LDO module is shown in Figure 30-1. The LDO module converts the input supply voltage to 5V (VDD5) as the power supply for built-in analog module. Internal LDO5 or external supply for VDD5 is selected by configuring VCC\_MODE. As shown in Figure 30-2, VCC\_MODE = 0 if VCC\_MODE is unchecked, where internal LDO supplies VDD5 voltage; and VCC\_MODE = 1 if VCC\_MODE is checked, where external 5V power supply is connected to VDD5 pin.

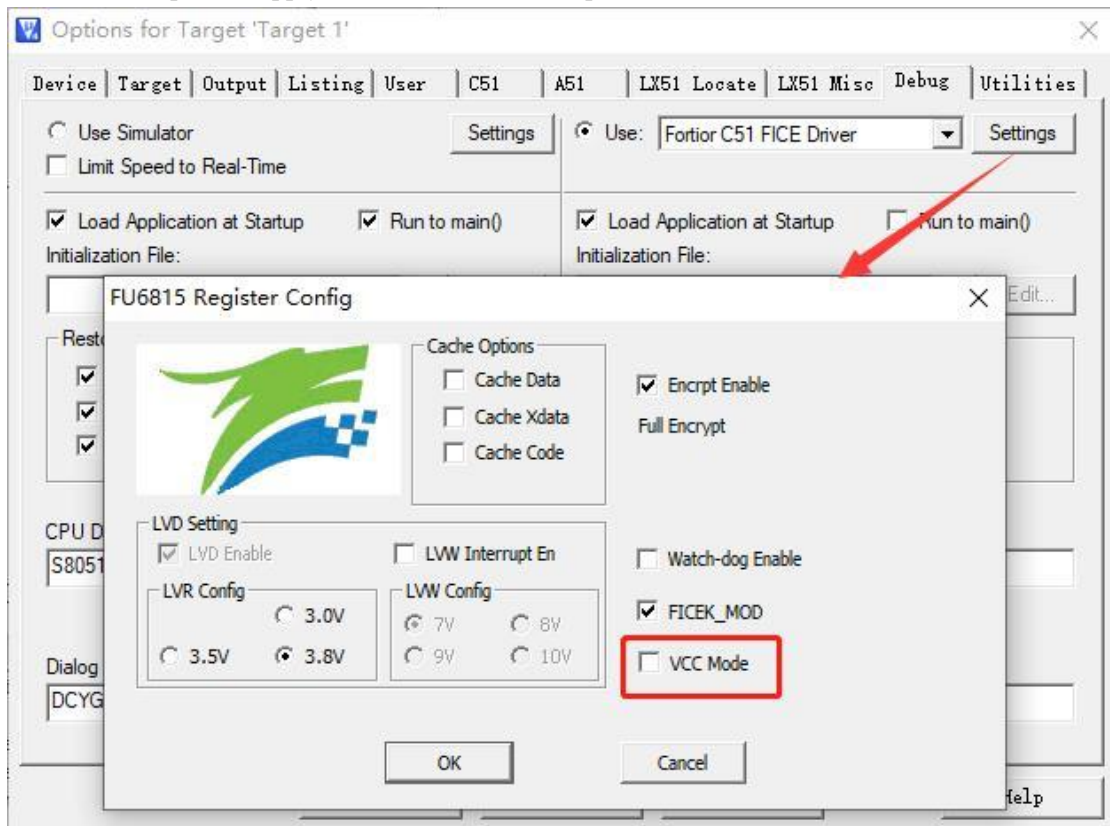


Figure 30-2 VCC\_MODE Configurations

## 30.2 Low Voltage Detector (LVD)

### 30.2.1 LVD Introduction

The low voltage detector has two main features: low voltage warning and low voltage reset.

### 30.2.2 LVD Operations

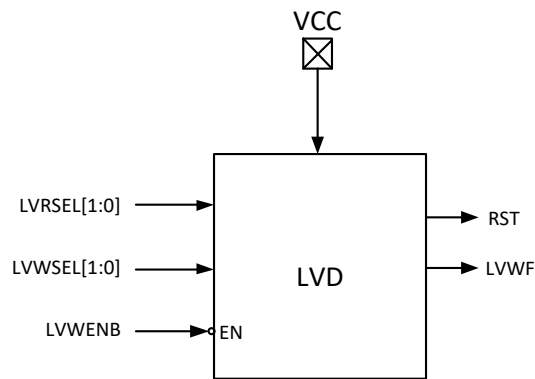


Figure 30-3 LV Detection Module

The operating instructions for LVD are as follows:

- LV warning and LV reset are always enabled by default.
- 7/8/9/10V can be selected for LV warning threshold. When the interrupt feature is enabled, an interrupt is triggered if VCC voltage is lower than the LV warning threshold.
- 3.0/3.5/3.8V can be selected for the LV reset threshold. The chip resets when VCC voltage is lower than the LV reset voltage threshold.

LV warning threshold, interrupt settings and LV reset threshold are configured through the debug tool, as shown in Figure 30-4.

LVR Config sets low voltage reset threshold, LVW Interrupt En enables low voltage interrupt, and LVW Config sets low voltage warning threshold.



Figure 30-4 Configurations of LV Warning Threshold, LV Interrupt and LV Reset Threshold

### 30.2.3 LVD Registers

#### 30.2.3.1 LVSR (0xDB)

Bit	7	6	5	4	3	2	1	0
Name	RSV		EXT0CFG			TSDF	LVWF	LVWIF
Type	-	-	R/W	R/W	R/W	R	R	R/W0
Reset	-	-	0	0	0	0	0	0
Bit	Name	Description						
[7:6]	RSV	Reserved						
[5:3]	EXT0CFG	INT0 Pin Selection 000:P0.0 001:P0.1 010:P0.2 011:P0.3 100:P1.1 101:P0.5 110:P0.6 111: CMP4 Output						
[2]	TSDF	Over Temperature State Indicator 0: The current temperature does not exceed the threshold 1: The current temperature exceeds the threshold  Note: This flag bit often works with TSD interrupt flag TCON[5]						
[1]	LVWF	VCC Low Voltage(LV) Flag This bit indicates whether the chip is in the low voltage state. 0: The chip is not in the LV warning state. 1: The chip is in the LV warning state.						

[0]	LVWIF	VCC LV Interrupt Flag Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0” 1: No effect  Note: This bit is not set to “1” by hardware when LVD interrupt is disabled.
-----	-------	--



## 31 Flash

### 31.1 Flash Introduction

The chip provides 32k bytes of Flash space. It supports page erasure, page pre-programming and write.

Main features:

- 128 sectors in total, each with a size of 256 bytes
- 16 pages in total, each with 8 sectors
- Last sector (address range: 0x7F00~0x7FFF) cannot be erased at any time
- 120ms~150ms for page erase
- Programming is enabled when FLA\_CR [FLAEN] is set to “1”, where page pre-programming, page erase or write and other Flash operations are activated with MOVX instructions.

### 31.2 Flash Operations

- Flash memory must be unlocked before erase and programming operations. The Flash software programming feature is activated after “0x5A” and “0x1F” are written to register FLA\_KEY in sequence. If the sequence is incorrect or other values are written, Flash space is frozen until the next reset. After unlocking, any write to the FLA\_CR register causes the FLA\_KEY to be locked again.
- CRC results change if Flash memory is rewritten during program execution.
- Page pre-programming must be done before page erase.
- Configuring FLA\_CR=0x23 enables page erase, FLA\_CR=0x25 enables page pre-programming and FLA\_CR=0x21 enables write operations.

Note: All interrupts must be disabled before self-programming to ensure the security of Flash operations and avoid mis-operation of Flash using MOVX instruction during interrupt processing.

### 31.3 Flash Registers

#### 31.3.1 FLA\_CR (0x85)

Bit	7	6	5	4	3	2	1	0
Name	RSV		FLAPAGE	FLAERR	RSV	FLAPRE	FLAERS	FLAEN
Type	-	-	R/W	R	-	R/W	R/W	R/W
Reset	-	-	0	0	-	0	0	0
Bit	Name	Description						
[7:6]	RSV	Reserved						
[5]	FLAPAGE	Page Operation Enable 0: Disable 1: Enable						
[4]	FLAERR	Programming Error Flag 0: Programming or pre-programming succeeds. 1: Programming or pre-programming fails.						
[3]	RSV	Reserved						

[2]	FLAPRE	Pre-programming Enable 0: Disable 1: Enable  Note: FLA_CR[FLAPRE] is valid only when FLA_CR[FLAEN] = 1.
[1]	FLAERS	Erase Enable 0: Disable 1: Enable  Note: FLA_CR[FLAERS] is valid only when FLA_CR[FLAEN] = 1.
[0]	FLAEN	Programming Enable 0: Disable 1: Enable

### 31.3.2 FLA\_KEY (0x84)

Bit	7	6	5	4	3	2	1	0
Name	FLA_KEY							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	FLA_KEY	Write: Write “0x5A” and “0x1F” in sequence to unlock Flash operations; Write any value to FLA_CR bit to lock Flash operations.						

Bit	7	6	5	4	3	2	1	0
Name	RSV						FLAKSTA	
Type	-	-	-	-	-	-	R	R
Reset	-	-	-	-	-	-	0	0
Bit	Name	Description						
[7:2]	RSV	Reserved						
[1:0]	FLAKSTA	Read: Flash Release Status 00: Locked 01: Write of 0x5A is done, waiting for 0x1F 10: Frozen 11: Released						

## 32 CRC

### 32.1 CRC Functional Block Diagram

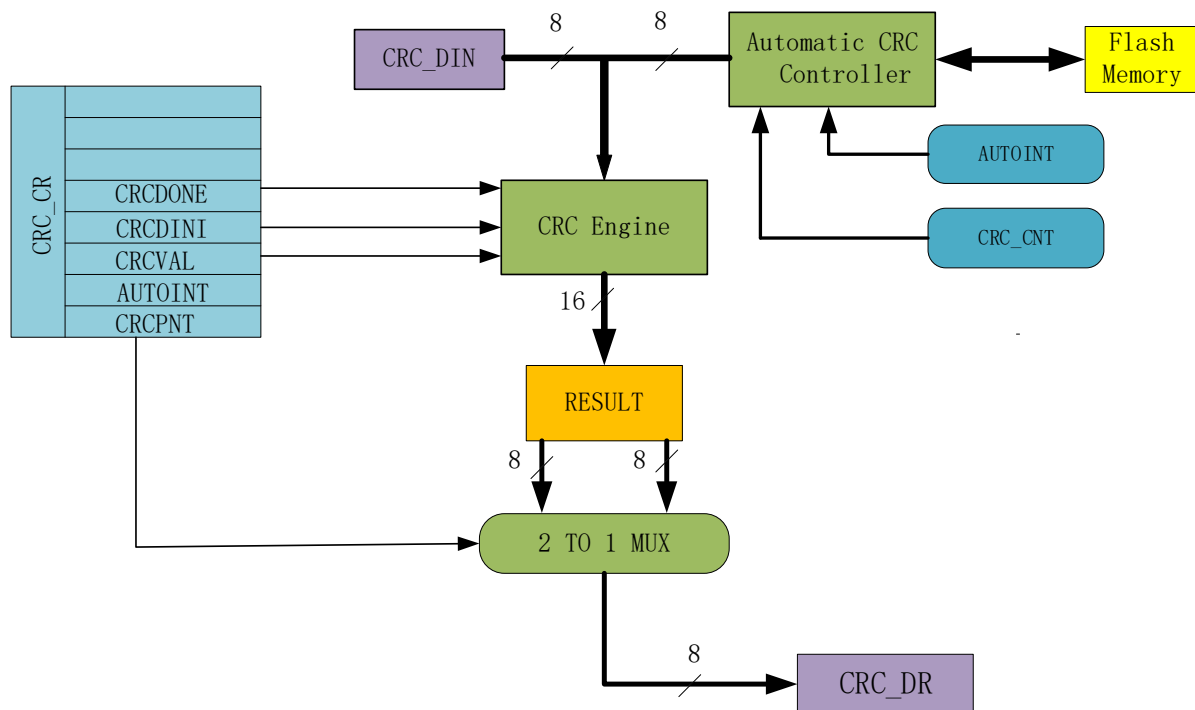


Figure 32-1 CRC Functional Block Diagram

CRC module outputs the result of CRC calculation for any 8-bit data based on a fixed polynomial. As shown in Figure 32-1, CRC receives the 8-bit data from CRC\_DIN and sends the 16-bit result to the internal register after the calculation is completed. The result can be indirectly accessed through CRC\_CR[CRCPNT] and CRC\_DR.

Table 32-1 CRC Criteria and Polynomials

S/N.	CRC Criteria	Polynomial	Hexadecimal Representation
1	CRC12	$x^{12}+x^{11}+x^3+x^2+x+1$	0x80F
2	CRC16	$x^{16}+x^{15}+x^2+1$	0x8005
3	CRC16/CCITT-FALSE	$x^{16}+x^{12}+x^5+1$	0x1021
4	CRC32	$x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^8+x^9+x^5+x^4+x+1$	0x04C11DB7

### 32.2 CRC16 Polynomial

The chip uses CRC16/CCITT-FALSE polynomial:  $x^{16}+x^{12}+x^5+1$ .

### 32.3 CRC16 Logic Diagram

The schematic diagram of CRC16 is shown in Figure 32-2. The chip implementation is based on parallel algorithm. For each input byte, MCU calculates the results within one system clock cycle.

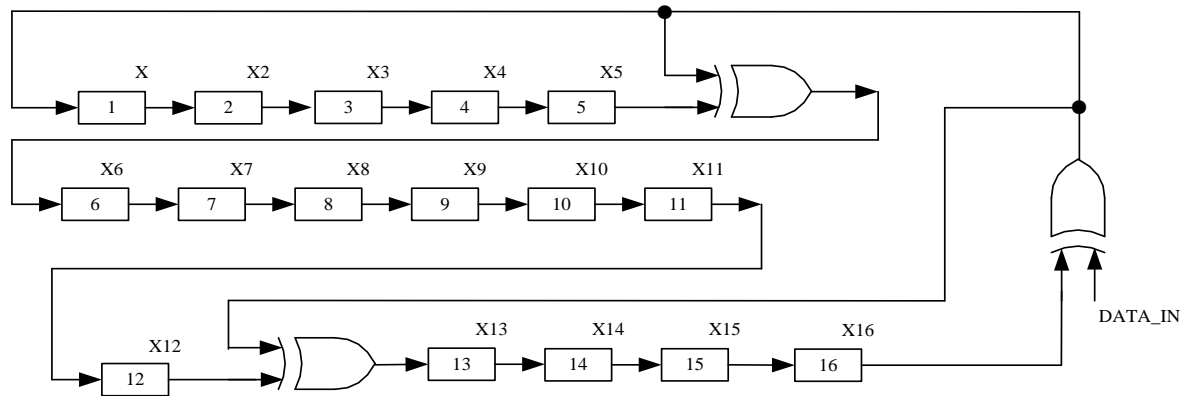


Figure 32-2 CRC16 Schematic Diagram

## 32.4 CRC Operations

### 32.4.1 CRC Calculation of Single Byte

CRC of a single byte is calculated as follows:

1. Initialize CRC\_DR with two options: Configure CRC\_CR[CRCVAL] and set CRC\_CR[CRCDINI] to “1”, with an initial value of 0x0000 or 0xFFFF. Or configure CRC\_CR[CRCPNT] and CRC\_DR, where any initial value can be set.
2. Write data to CRC\_DIN, and the CRC calculation is completed in the next clock cycle;
3. Read CRC results: Configure CRC\_CR[CRCPNT] = 1, and read off CRC\_DR in software to get the high bytes. Configure CRC\_CR[CRCPNT] = 0, and read off CRC\_DR to get the low bytes.

### 32.4.2 CRC Calculation of ROM Sector

CRC of a continuous area of data in the ROM is calculated as follows:

1. Initialize CRC\_DR, in the same way as that of single-byte CRC calculation;
2. Configure CRC\_BEG to define starting sector of the ROM to be calculated;
3. Configure CRC\_CNT to set the offset from the starting sector to the ending sector;
4. Write “1” to CRC\_CR[AUTOINT] and keep other bits unchanged. The calculation starts automatically;
5. Read the CRC results.

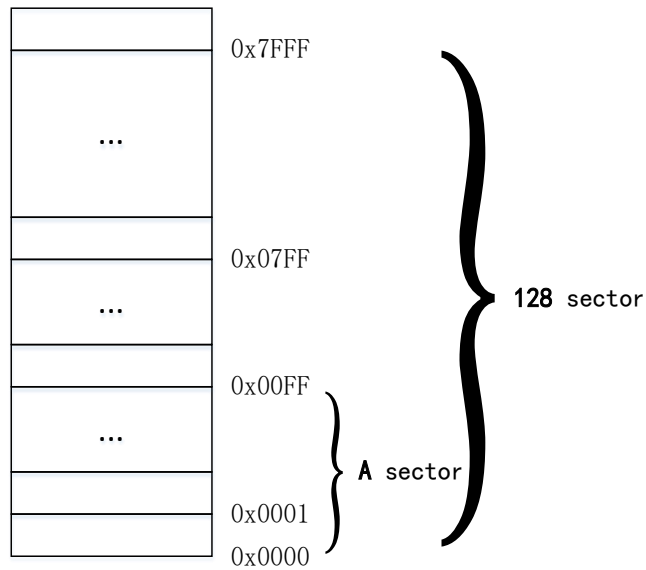


Figure 32-3 ROM Sectors

As shown in Figure 32-3, ROM contains 32k bytes and is divided into 128 sectors, numbered from sector0 to sector127. Each sector contains 256 bytes. For CRC calculation of sectors, the value of CRC\_BEG (the starting sector) can be any value falling between 0x00 and 0xFF, including 0x00 and 0x7F. The CRC\_CNT (total number of sectors to be calculated) can be any value between 0x00~0x7F, including 0x00 and 0xFF.

As CRC\_BEG increases, CRC\_CNT decreases accordingly. For example, if CRC\_BEG is 0x7F, CRC\_CNT can be 0x00 only, i.e., the CRC value of the data in the last sector is calculated. In this case, if CRC\_CNT is large, CRC controller will automatically limits the number of sectors to be calculated. Finally, CRC module only calculates CRC value of the last sector.

## 32.5 CRC Registers

### 32.5.1 CRC\_CR (0x4022)

Bit	7	6	5	4	3	2	1	0
Name	RSV			CRCDONE	CRCDINI	CRCVAL	AUTOINT	CRCPNT
Type	-	-	-	R	W1	R/W	W1	R/W
Reset	-	-	-	1	0	0	0	0
Bit	Name	Description						
[7:5]	RSV	Reserved						
[4]	CRCDONE	CRC Sector Calculation Completion Flag During the calculation, this bit is automatically set to “0” and the software program stops. In other cases, this bit is automatically set to “1” by the hardware, so the software always returns “1” when reading this bit.						
[3]	CRCDINI	CRC Result Initialization Trigger 0: No effect 1: CRC result initialization is triggered.						
[2]	CRCVAL	CRC Result Initialization Selection 0: CRC result is initialized to 0x0000. 1: CRC result is initialized to 0xFFFF.						
[1]	AUTOINT	CRC Sector Calculation Launch 0: No effect 1: Launch CRC Batch calculation See section CRC Calculation of ROM Sector.						
[0]	CRCPNT	CRC Result Pointer 0: Read CRC_DR to access 8 low-order bits of the 16-bit CRC result 1: Read CRC_DR to access 8 high-order bits of the 16-bit CRC result						

Note: CRC\_CR[AUTOINT] is set to “0” to perform single-byte CRC checksum.

### 32.5.2 CRC\_DIN (0x4021)

Bit	7	6	5	4	3	2	1	0
Name	CRC_DIN							
Type	W	W	W	W	W	W	W	W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						
[7:0]	CRC_DIN	CRC Input Data Each time a data frame is written to this register, CRC module automatically calculates a new CRC result based on the existing CRC result, and overwrites the original one.  Note: It is a virtual register, so the written data is not saved. 0x00 is returned when the address is accessed.						

### 32.5.3 CRC\_DR (0x4023)

Bit	7	6	5	4	3	2	1	0
Name	CRC_DR							
Type	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0
Bit	Name	Description						

[7:0]	CRC_DR	CRC Result Output Each time this register is read or written, the configuration of CRC_CR[CRCPNT] determines whether to access the high or low 8 bits of the CRC result.
-------	--------	---

### 32.5.4 CRC\_BEG (0x4024)

Bit	7	6	5	4	3	2	1	0
Name	RSV	CRC_BEG						
Type	-	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	RSV	Reserved						
[6:0]	CRC_BEG	First ROM Sector Pending Automatic CRC Calculation Example: If CRC_BEG is set to "1", CRC calculation starts from location 1*256 = 256, or rather from the first byte of sector 2.						

### 32.5.5 CRC\_CNT (0x4025)

Bit	7	6	5	4	3	2	1	0
Name	RSV	CRC_CNT						
Type	-	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	-	0	0	0	0	0	0	0
Bit	Name	Description						
[7]	RSV	Reserved						
[6:0]	CRC_CNT	Offset of Sector Pending Automatic CRC Calculation This bit defines the offset of ROM sector for CRC calculation and determines the last sector pending CRC calculation.						

## 33 Sleep Mode

### 33.1 Introduction

The chip operates in three modes: normal mode, standby mode and sleep mode. These modes are selected by setting PCON[IDLE] and PCON[STOP].

The operating states of the module under different power modes are summarized in Table 33-1.

Table 33-1 Power Consumption Modes

Power Mode	Description	Wakeup Source	Power Consumption Performance
Normal	All modules work at full speed except for peripherals that are disabled	NA	High power consumption with best performance
Standby	CPU clock stops and other functional modules are either enabled or disabled depending on their control bit setting. WDT stops.	Any interrupt; Reset/Debug on external interrupt	Low power performance with flexible performance
Sleep	Flash Deep Sleep. The analog fast clock circuit is disconnected and MCU software shall ensure that ADC, FOC, and driver modules are disabled before the chip enters the Sleep Mode. WDT is disabled.	External interrupt; RTC interrupt; Level changes of P4.7 in IO mode; Reset/Debug on external interrupt	Extremely low power performance with flexible performance

Note: It is recommended to insert 3 null statements in the Sleep mode.

```
PCON = 0x02;
```

```
_nop_();
```

```
_nop_();
```

```
_nop_();
```



## 33.2 Sleep Mode Register

### 33.2.1 PCON(0x87)

Bit	7	6	5	4	3	2	1	0
Name	RSV		GF3	GF2	GF1	RSV	STOP	IDLE
Type	-	-	R/W	R/W	R/W	-	R/W	R/W
Reset	-	-	0	0	0	-	0	0
Bit	Name	Description						
[7:6]	RSV	Reserved						
[5]	GF3	General-purpose flag bit 3						
[4]	GF2	General-purpose flag bit 2						
[3]	GF1	General-purpose flag bit 1						
[2]	RSV	Reserved						
[1]	STOP	A write of “1” makes the chip enter the sleep mode. The bit is automatically cleared to “0” by hardware after wakeup.						
[0]	IDLE	A write of “1” makes the chip enter the standby mode. The bit is automatically cleared to “0” by hardware after wakeup.						

Power Consumption Mode PCON[STOP:IDLE]:

00: Normal

01: Standby

1X: Sleep

## 34 Code Protection

### 34.1 Introduction

The chip supports Flash space encryption to protect your software intellectual property and avoid unauthorized access. When Flash memory is encrypted, the data inside cannot be read, and data consistency can be evaluated by CRC check module only.

### 34.2 Operating Instructions

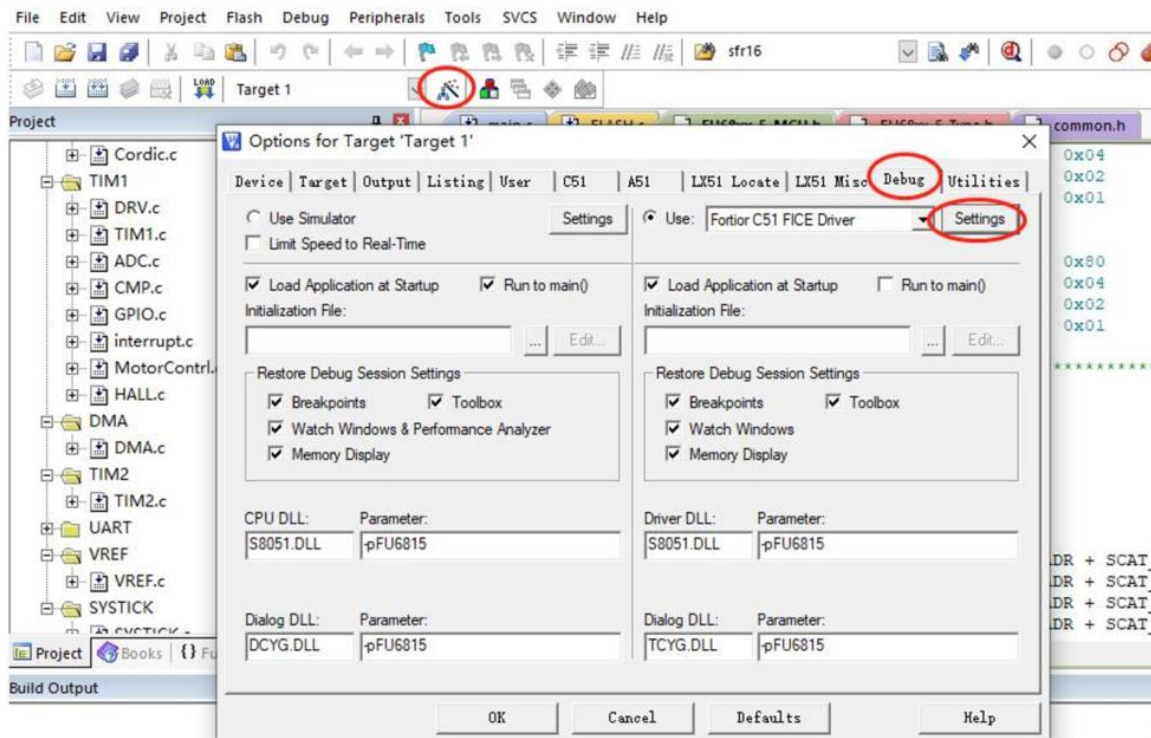


Figure 34-1 Code Protection Configurations

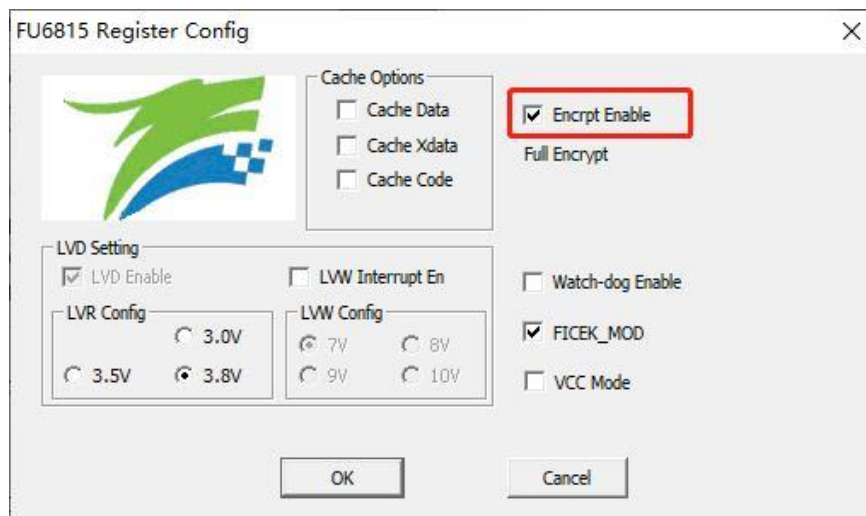


Figure 34-2 Full Code Protection Mode

Operation steps are as follows:

1. Start 8051 IDE, enter Target Options and select Debug tab. As shown in Figure 34-1, click Settings to proceed with the setting;
2. Select the options as shown in Figure 34-2, and click OK. Then compile the project and download it. Get the BIN file and program it to Flash.

**35 Revision History**

<b>Rev.</b>	<b>Description</b>	<b>Date</b>	<b>Prepared By</b>
V2.0	First release. Translated from Chinese version 2.0.	2023/07/12	Eric Deng
V3.0	<ol style="list-style-type: none"> <li>1. Added the chip FU6864L;</li> <li>2. Updated IO Type and descriptions on RXD2S2, RXD2, RXD2S, RXD and RXDS pins;</li> <li>3. Updated Figure 35-1 LQFP48_7X7 Package Drawings and Dimensions;</li> <li>4. Updated Figure 35-2 QFN56_7X7 Package Drawings and Dimensions;</li> <li>5. Deselected “External Slow Clock” for FU6864Q in section 4 Ordering Information;</li> <li>6. Added “The corresponding registers shall be enabled before using UART feature. See section 22.3.16 PH_SEL (0x404C) ([6] and [5] bits) ~ section 22.3.17 PH_SEL1 ([7:6] bit) for details.” in section 10.2 UART Operations;</li> <li>7. Added section 19 Clock and moved section 20.4 Clock Calibration to section 19;</li> <li>8. Modified figures and descriptions on PGA single-ended input mode of AMP0/AMP1/AMP2/AMP3;</li> <li>9. Standardized document format.</li> </ol>	2023/10/18	Eric Deng

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