

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 nth port of the Portm. P0.0 indicates the 0th 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 ² 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/FU6815T/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
 - FU6815T: 19
 - 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 (FU6815L/FU6815T/FU6865Q): 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, tailwind/headwind detection, 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*I²C
 - 2*UARTs, supporting single-wire mode (FU6815L/FU6865Q)
 - 1*UART, supporting single-wire mode (FU6815T/FU6864Q/FU6864L)
 - Dual-channel DMA: supporting data transmission via I²C/SPI/UART (FU6815L/FU6865Q)
 - Dual-channel DMA: supporting data transmission via I²C/UART (FU6815T/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:
 - ◆ FU6815L/FU6865Q: 14
 - ◆ FU6815T/FU6864Q: 12
 - ◆ FU6864L: 13 (Among them, AD0 is an 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 channels: Single-channel 9-bit, single-channel 8-bit, single-channel 6-bit
- Driver Type
 - FU6815L/FU6815T: PWM output
 - FU6865Q/FU6864Q/FU6864L: Built-in MOSFET driver with 6N pre-driver output
- FOC module supports single/dual/triple-shunt current sampling
- FU6815L: 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.
- FU6815T: 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/FU6815T), pre-driver (FU6865Q/FU6864Q/FU6864L), high-speed ADC, CRC, SPI, I²C, UART, Timers and 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) and FU6815T (TSSOP28).

FU6865 includes FU6865Q (QFN56).

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

1.4 Functional Block Diagram

1.4.1 FU6815L

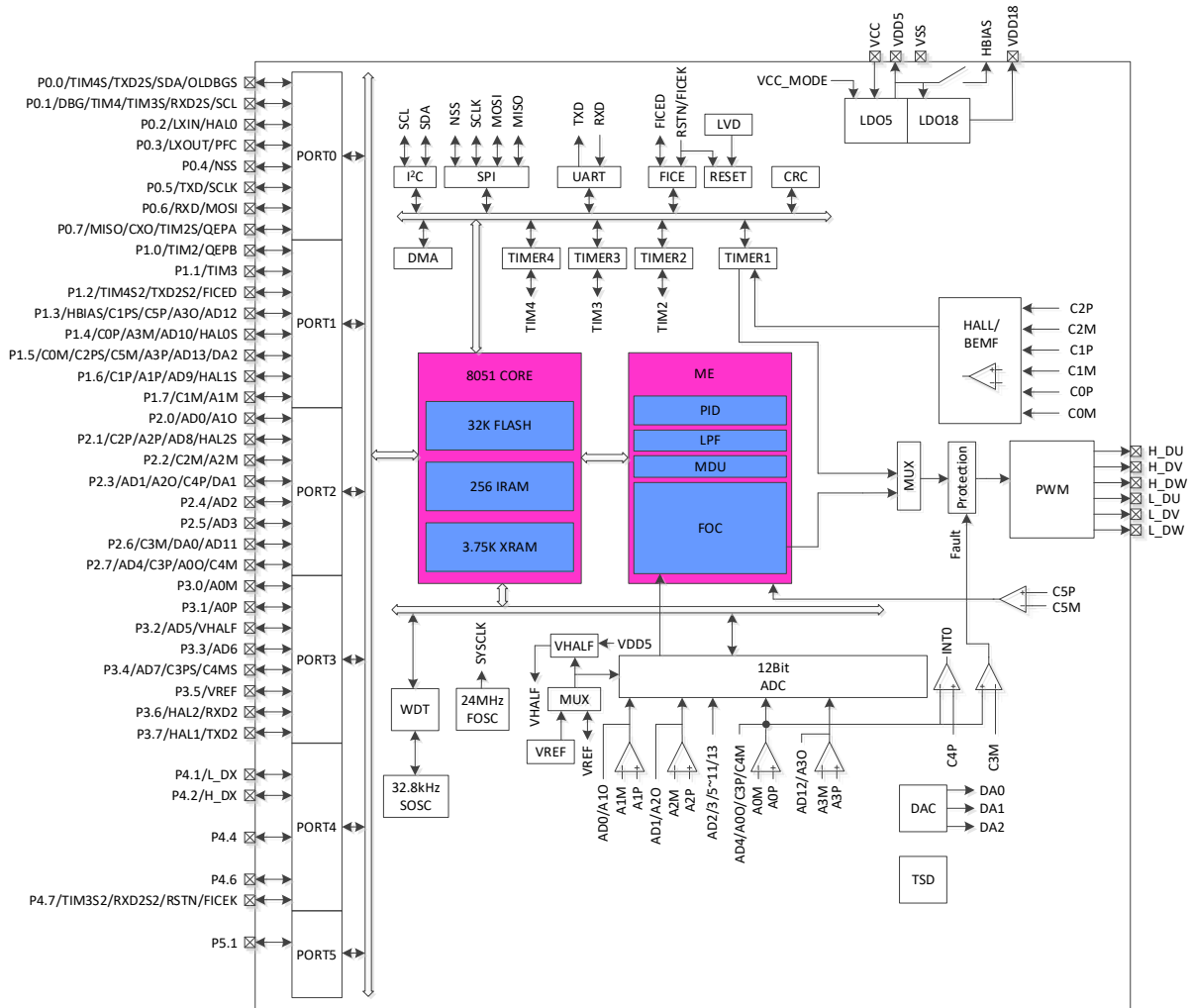
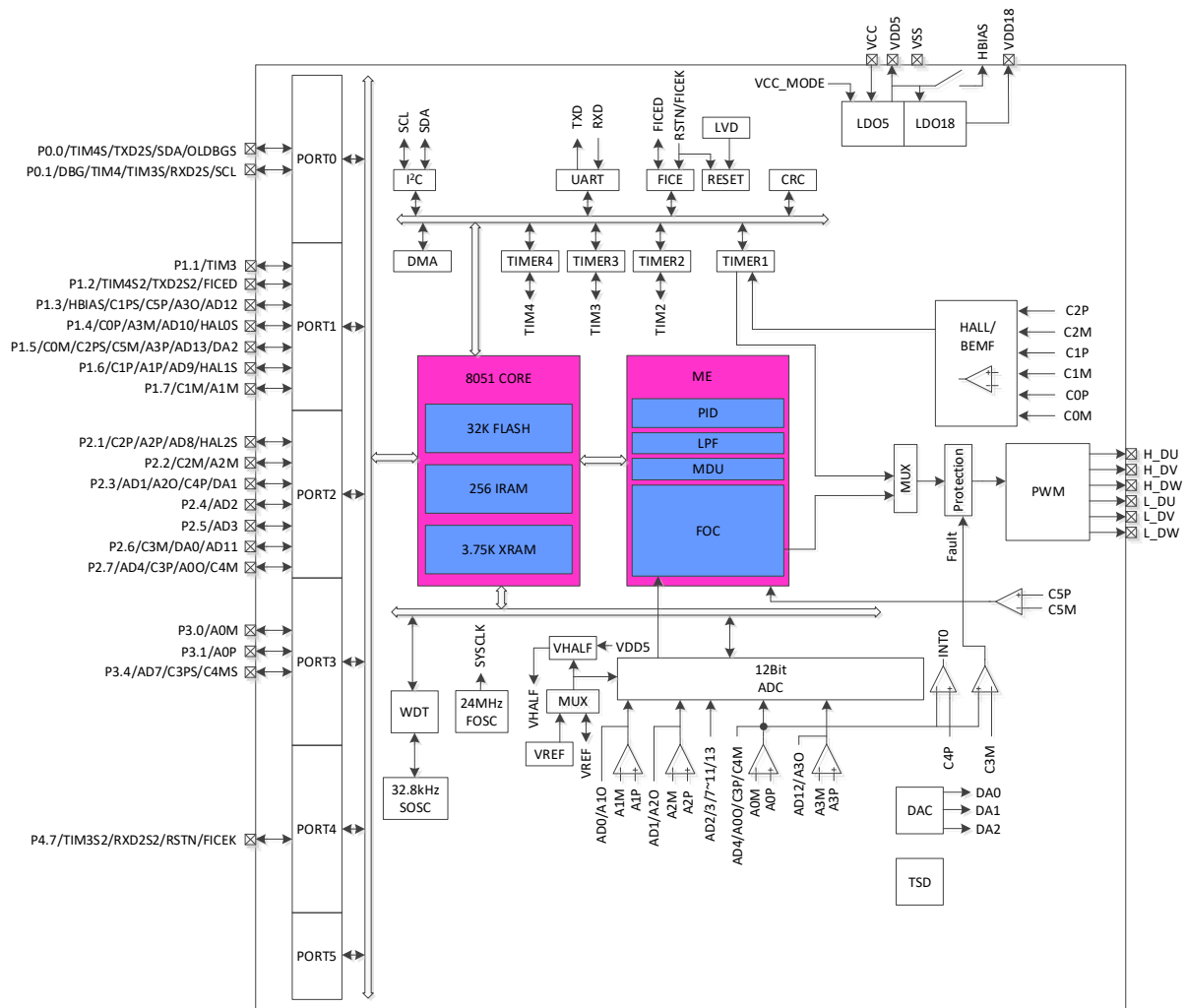


Figure 1-1 Functional Block Diagram of FU6815L

1.4.2 FU6815T



1.4.3 FU6865Q

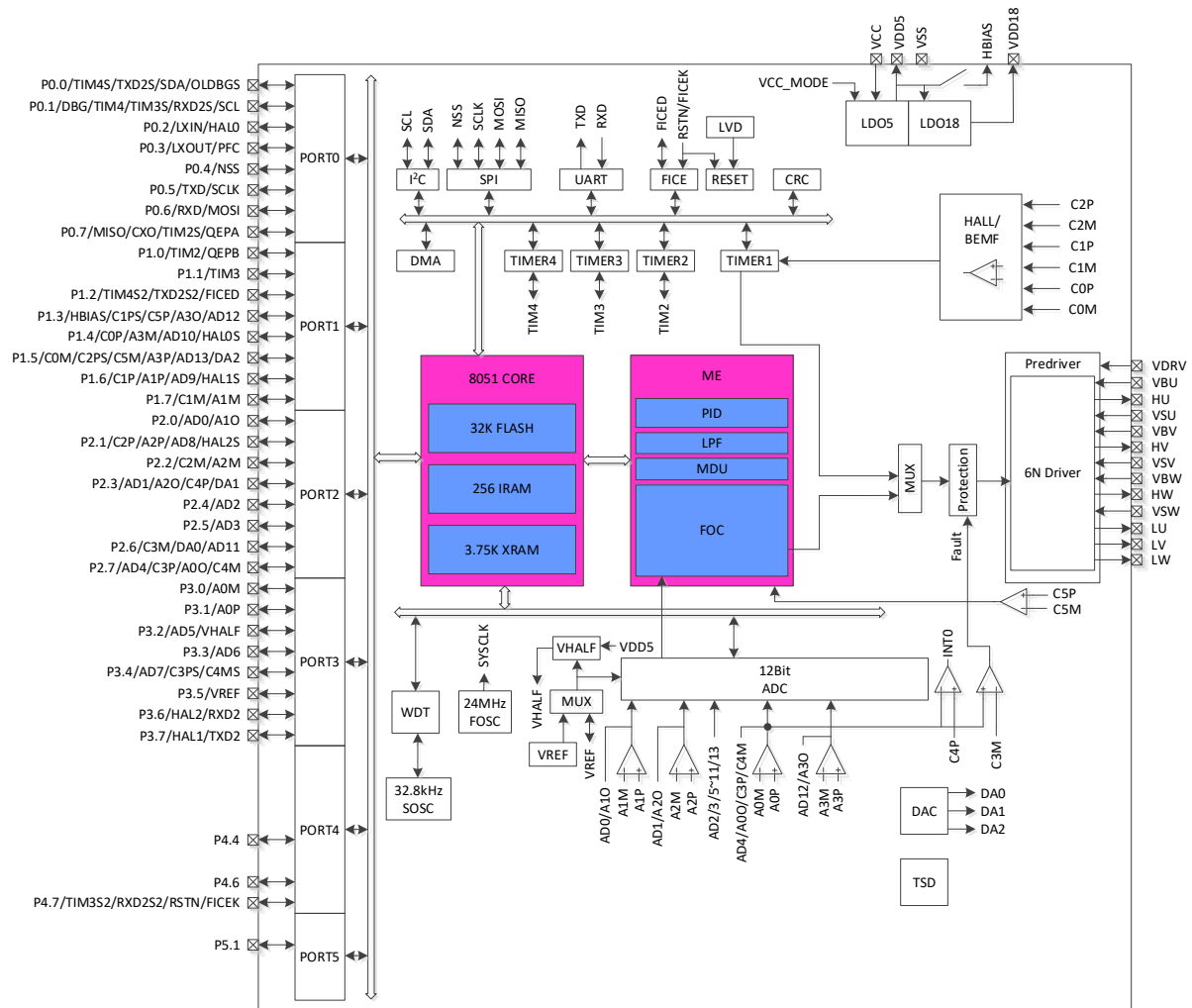


Figure 1-3 Functional Block Diagram of FU6865Q

1.4.4 FU6864Q

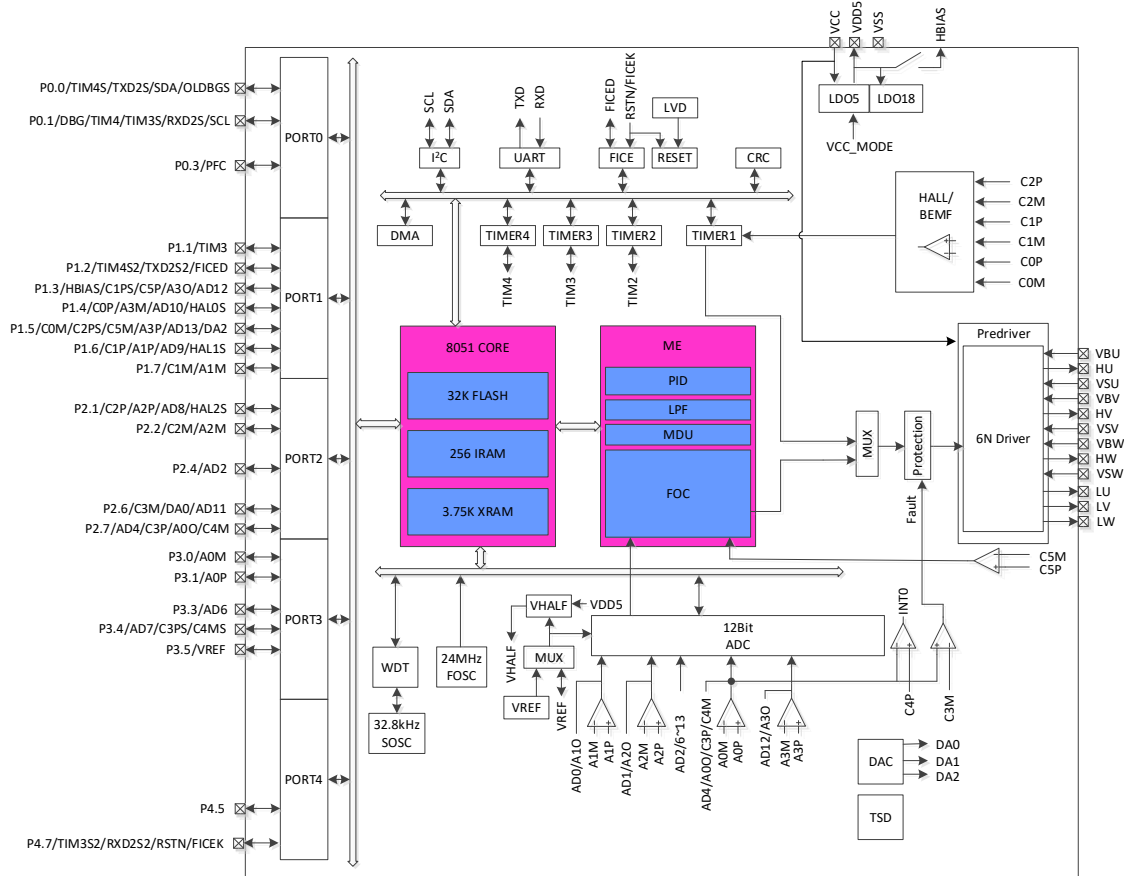


Figure 1-4 Functional Block Diagram of FU6864Q

1.4.5 FU6864L

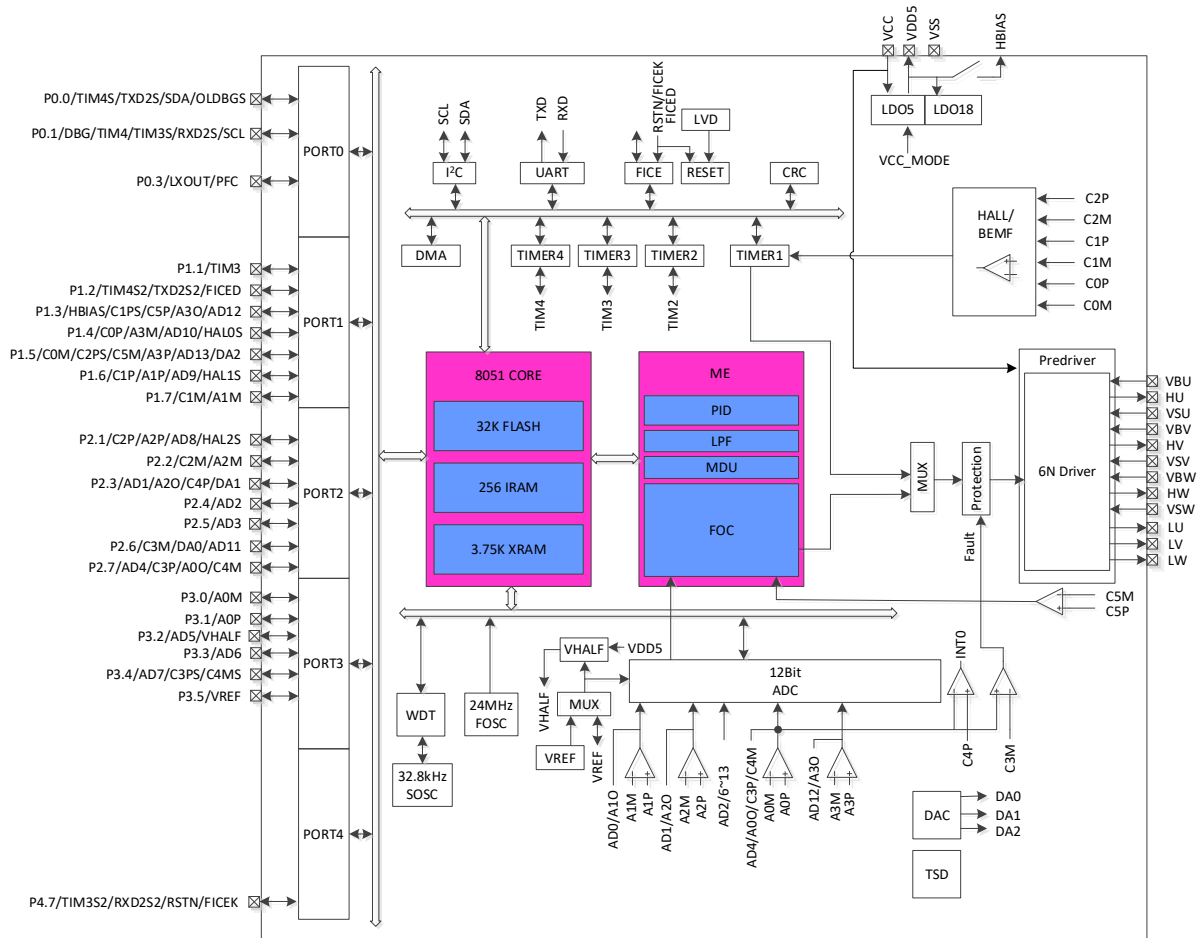


Figure 1-5 Functional Block Diagram of FU6864L

1.5 Memory Organization

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

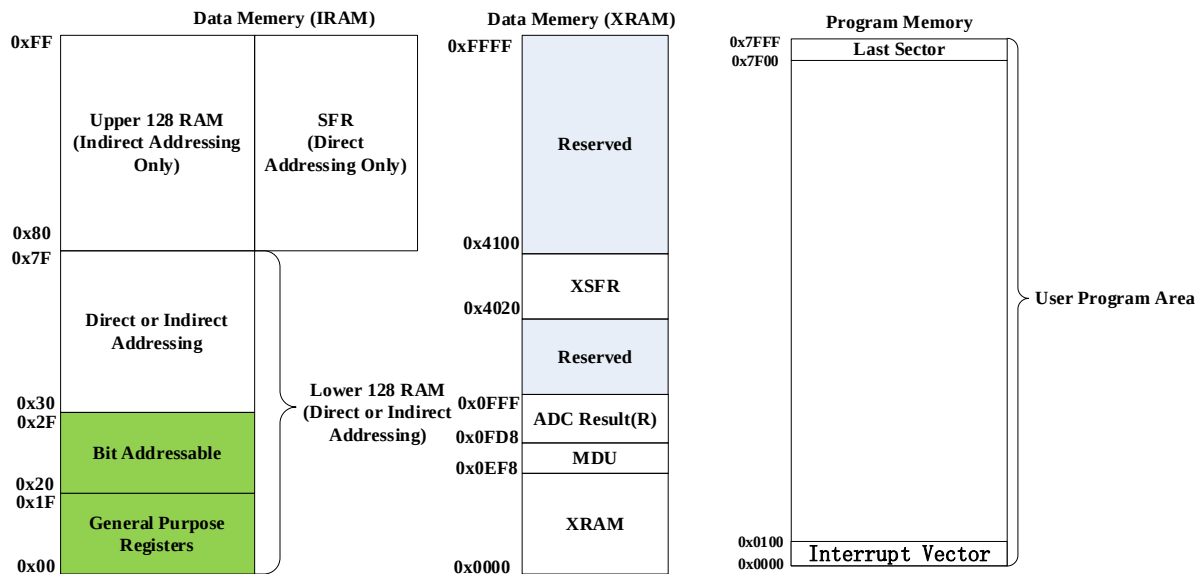


Figure 1-6 Memory Organization

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 1-6.

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	UDC_UKMINL	IAC__REFH	IAC__REFL	IAC__UKH	IAC__UKL
			PFC_CR1	PFC_KM				
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_ARRL	PFC_DRH	PFC_DRL
					PFC_UAVGH	PFC_UAVGL		
0x40D8	FOC__POWH	FOC__POWL	FOC__IAMAXH	FOC__IAMAXL	FOC__IBMAXH	FOC__IBMAXL	FOC__ICMAXH	FOC__ICMAXL
	FOC_EOMEKLPF							
0x40D0	FOC__EALPH	FOC__EALPL	FOC__EBETH	FOC__EBETL	FOC__EOMEH	FOC__EOMEL	FOC__UQEXH	FOC__UQEXL
							FOC_KFGH	FOC_KFGL
0x40C8	FOC__IBH	FOC__IBL	FOC__IAH	FOC__IAL	FOC__THETAH	FOC__THETAL	FOC__ETHETAH	FOC__ETHETAL
	FOC__LQH	FOC__LQL	FOC__LDH	FOC__LDL				
0x40C0	FOC__IBETH	FOC__IBETL	FOC__VBETH	FOC__VBETL	FOC__VALPH	FOC__VALPL	FOC__ICH	FOC__ICL
	FOC__IQ_LPFK	FOC__ID_LPFK	FOC__UDCPSH	FOC__UDCPSL	FOC__UQCPSH	FOC__UQCPSL	FOC__FLUXH	FOC__FLUXL
0x40B8	FOC__UDH	FOC__UDL	FOC__UQH	FOC__UQL	FOC__IDH	FOC__IDL	FOC__IQH	FOC__IQL
0x40B0	FOC__DMAXH	FOC__DMAXL	FOC__DMINH	FOC__DMINL	FOC__QMAXH	FOC__QMAXL	FOC__QMINH	FOC__QMINL
	FOC__OMEESTH	FOC__OMEESTL	FOC__ATAN_THETAH	FOC__ATAN_THETAL				
0x40A8	FOC__RTHESTEPH	FOC__RTHESTEPL	FOC__RTHEACCH	FOC__RTHEACCL	FOC__RTHECNT	FOC__THECOR	FOC__THECOMPH	FOC__THECOMPL
			FOC__EOMELPFH	FOC__EOMELPFL		CMP__SAMR	FOC__EMFH	FOC__EMFL
0x40A0	FOC_CR1	FOC_CR2	FOC_TSMIN	FOC_TGLI	FOC_TBLO	FOC_TRGDLY	FOC_CSOH	FOC_CSOL
0x4098	FOC__UDCFLTH	FOC__UDCFLTL	PFC__UACH	PFC__UACL	PFC__IACH	PFC__IACL	FOC_CR3	FOC_CR0
	TIM1__ITRIPH	TIM1__ITRIPL						
0x4090	FOC__IDREFH	FOC__IDREFL	FOC__IQREFH	FOC__IQREFL	FOC__QKPH	FOC__QKPL	FOC__QKIH	FOC__QKIL
	TIM1__URESH	TIM1__URES	TIM1_KRMAS	TIM1_KFMIN	TIM1_KFH	TIM1_KFL	TIM1_KRH	TIM1_KRL
0x4088	FOC_EK3H	FOC_EK3L	FOC_EK4H	FOC_EK4L	FOC_EK1H	FOC_EK1L	FOC_EK2H	FOC_EK2L

Addr	0(8)	1(9)	2(A)	3(B)	4(C)	5(D)	6(E)	7(F)
	TIM1_RARRH	TIM1_RARRL	TIM1_RCNTRH	TIM1_RCNTRL	TIM1_UCOPH	TIM1_UCOPL	TIM1_UFLPH	TIM1_UFLPL
0x4080	FOC_FBASEH	FOC_FBASEL	FOC_EFREQACCH	FOC_EFREQACCL	FOC_EFREQMINH	FOC_EFRQMINL	FOC_EFREQHOLDH	FOC_EFREQHOLDL
	TIM1_DBR7H	TIM1_DBR7L	TIM1_BCNTRH	TIM1_BCNTRL	TIM1_BCCRH	TIM1_BCCRL	TIM1_BARRH	TIM1_BARRL
0x4078	FOC_KSLIDEH	FOC_KSLIDEL	FOC_EKLPMFMINH	FOC_EKLPMFMINL	FOC_DKIH	FOC_DKIL	FOC_OMEKLPFH	FOC_OMEKLPFL
	TIM1_DBR3H	TIM1_DBR3L	TIM1_DBR4H	TIM1_DBR4L	TIM1_DBR5H	TIM1_DBR5L	TIM1_DBR6H	TIM1_DBR6L
0x4070	TIM1_BCORH	TIM1_BCORL	TIM1_CR5		FOC_EKPH	FOC_EKPL	FOC_EKIH	FOC_EKIL
	FOC_DKPH	FOC_DKPL			TIM1_DBR1H	TIM1_DBR1L	TIM1_DBR2H	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
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	

Addr	0(8)	1(9)	2(A)	3(B)	4(C)	5(D)	6(E)	7(F)
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	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 a 1 μ F external 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	Description
P3.5/ VREF	12	DB/ AB	GPIO ADC external VREF input or internal VREF output, with a 1 μ F ~ 4.7 μ F external 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/ OLDBGs	17	DB/ DB/ DB/ DO/ DO	GPIO, configurable as INT0 input Timer4 input/output after function switching UART2 TXD output after function switching I ² C SDA, configured as collector open-drain output SPI 1-wire debug output after function switching
P0.1/ DBG/ TIM4/ TIM3S/ RXD2S/ SCL	18	DB/ DO/ DB/ 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 ² 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

Pin	FU6815L LQFP48	IO Type	Description
H_DV	33	DO	High-side V-phase PWM output
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. - 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.
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	1.85V LDO output with a 1μF ~ 4.7μF external 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	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

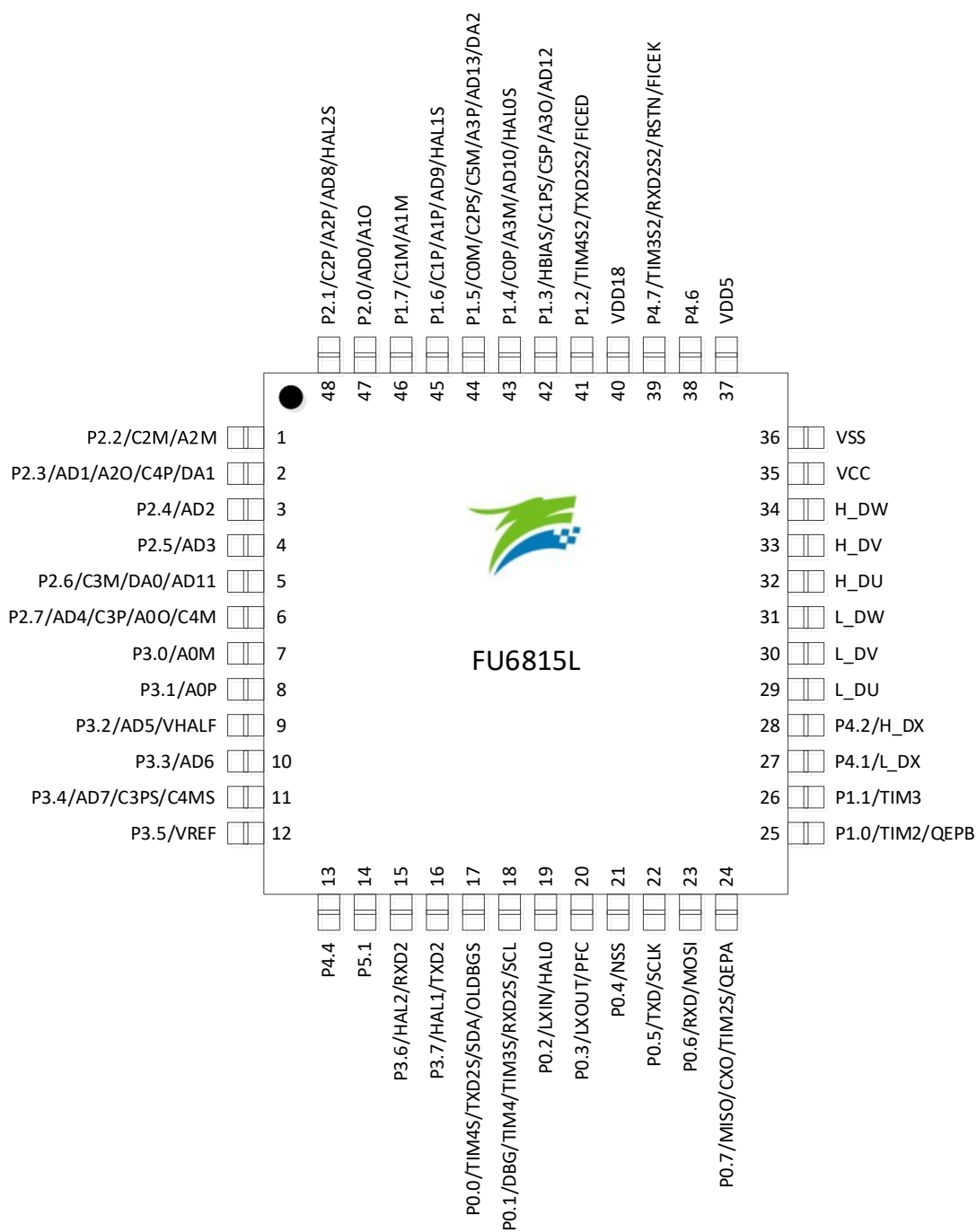


Figure 2-1 FU6815L LQFP48 Pinout Diagram

2.3 FU6815T TSSOP28 Pins

Table 2-2 FU6815T TSSOP28 Pin Descriptions

Pin	FU6815T TSSOP28	IO Type	Description
P1.4/ C0P/ A3M/ AD10/ HAL0S	1	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	2	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 input without buffer output
P1.6/ C1P/ A1P/ AD9/ HAL1S	3	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	4	DB/ AI/ AI	GPIO, configurable as INT1 input CMP1 negative input AMP1 negative input
P2.1/ C2P/ A2P/ AD8/ HAL2S	5	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	6	DB/ AI/ AI	GPIO CMP2 negative input AMP2 negative input
P2.4/ AD2	7	DB/ AI	GPIO Input of ADC channel 2 for bus voltage sampling
P2.5/ AD3	8	DB/ AI	GPIO Input of ADC channel 3
P2.6/ C3M/ DA0/ AD11	9	DB/ AI/ AO/ AI	GPIO CMP3 negative input DAC0 output without Buffer output Input of ADC channel 11
P2.7/ AD4/ C3P/ A0O/ C4M	10	DB/ AI/ AI/ AO/ AI	GPIO Input of ADC channel 2 for bus current sampling CMP3 positive input AMP0 output CMP4 negative input
P3.0/ A0M	11	DB/ AI	GPIO AMP0 negative input
P3.1/ A0P	12	DB/ AI	GPIO AMP0 positive input
P3.4/ AD7/ C3PS/ C4MS	13	DB/ AI/ AI/ AI	GPIO Input of ADC channel 7 CMP3 positive input after function switching CMP3 negative input after function switching
P0.0/ TIM4S/ TXD2S/ SDA/	14	DB/ DB/ DB/ DO/	GPIO, configurable as INT0 input Timer4 input or output after function switching UART2 TXD output after function switching I ² C SDA, configured as open-drain output

Pin	FU6815T TSSOP28	IO Type	Description
OLDBGS		DO	SPI 1-wire debug output after function switching
P0.1/ DBG/ TIM4/ TIM3S/ RXD2S/ SCL	15	DB/ DO/ DB/ DB/ DB/ DB	GPIO, configurable as INT0 input Debug port Timer4 input or output Timer3 input or output after function switching UART RXD input in two-wire mode or TXD output/RXD input in single-wire mode after function switching I ² C SCL, configured as open-drain output
P1.1/ TIM3	16	DB/ DB	GPIO, configurable as INT0/INT1 input, Timer3 input or output, configured as open-drain output
L_DU	17	DO	PWM Low-side U-phase output
L_DV	18	DO	PWM Low-side V-phase output
L_DW	19	DO	PWM Low-side W-phase output
H_DU	20	DO	PWM High-side U-phase output
H_DV	21	DO	PWM High-side V-phase output
H_DW	22	DO	PWM High-side W-phase output
VCC	23	P	Power input. The voltage range is determined by VCC_MODE, with an external filter capacitor of 4.7μF or above. - 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.
VSS	24	P	Ground
VDD5	25	P	Medium voltage power supply input or internal 5V LDO output power supply, determined by VCC_MODE, power supply connection method refer to the VCC pin description, and external capacitor ≥ 1 μF. Medium voltage power supply input or internal 5V LDO output power supply, determined by VCC_MODE. - When VCC_MODE = 0, enable internal LD0 to output 5V power supply; - When VCC_MODE = 1, disable internal LD0 and pour in external 3V~5.5V power supply
P4.7/ TIM3S2/ RXD2S2/ RSTN/ FICEK	26	DI/ DI/ DB/ DI/ DI	GPIO input only, configured with pull-up or pull-down resistors Timer3 input after function switching UART 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	27	DB/ DB/ DO/ DB	GPIO, configurable as INT1 input Timer4 input or output after function switching UART2 TXD output after function switching FICE SDA
P1.3/ HBIAS/ C1PS/ C5P/ A3O/ AD12	28	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

2.4 FU6815T TSSOP28 Pinout Diagram

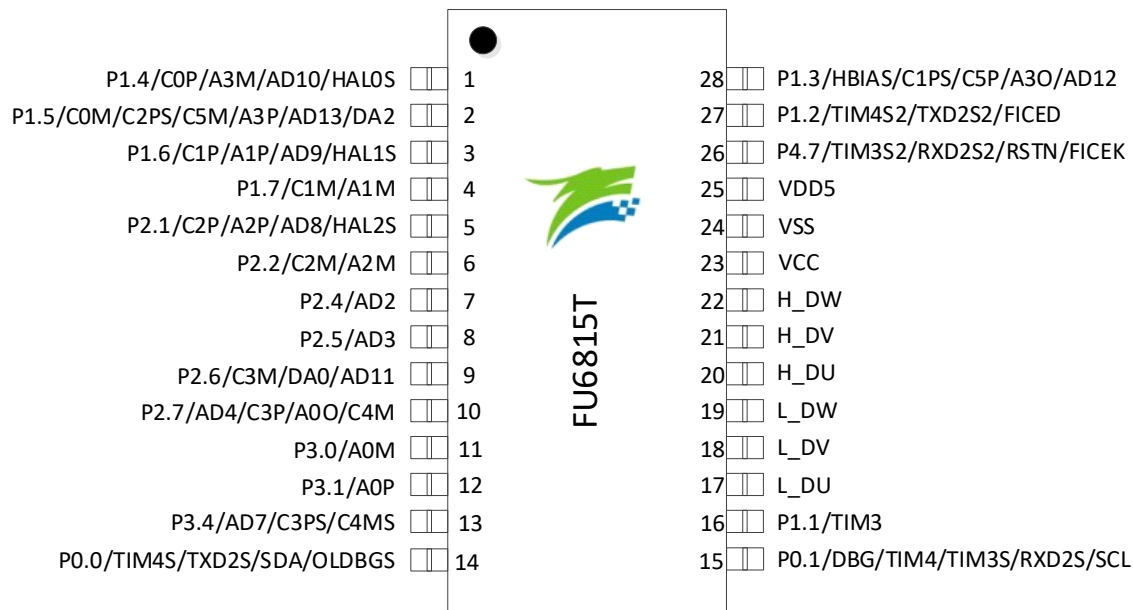


Figure 2-2 FU6815T TSSOP28 Pinout Diagram

2.5 FU6865Q QFN56 Pins

Table 2-3 FU6865Q QFN56 Pin Descriptions

Pin	FU6865Q QFN56	IO Type	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
VBV	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
VBW	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 4.7μF or above. - 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.
VSS	11	P	Ground
VDD5	12	P	Medium voltage power supply input or internal 5V LDO output power supply, determined by VCC_MODE, power supply connection method refer to the VCC pin description, and external capacitor ≥1 μ F. Medium voltage power supply input or internal 5V LDO output power supply, determined by VCC_MODE. When VCC_MODE = 0, enable internal LD0 to output 5V power supply;

Pin	FU6865Q QFN56	IO Type	Description
			■ When VCC_MODE = 0, disable internal LD0 and pour in external 3V~5.5V power supply
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 a 1μF ~ 4.7μF external 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
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	26	DB/ AI/ AO	GPIO Input of ADC channel 1 AMP2 output CMP4 positive input

Pin	FU6865Q QFN56	IO Type	Description
C4P/ DA1		AI/ DO	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 a 1 μ F external 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
P3.5/ VREF	36	DB/ AB	GPIO ADC external VREF input or internal VREF output, with a 1 μ F ~ 4.7 μ F external 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/ OLDBGS	41	DO/ DB/ DB/ DO/ DO	GPIO, configurable as INT0 input Timer4 input/output after function switching UART2 TXD output after function switching I ² C SDA, configured as collector open-drain output SPI single-wire debug output after function switching
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 ² 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

Pin	FU6865Q QFN56	IO Type	Description
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 a 1μF ~ 10μF external 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

2.6 FU6865Q QFN56 Pinout Diagram

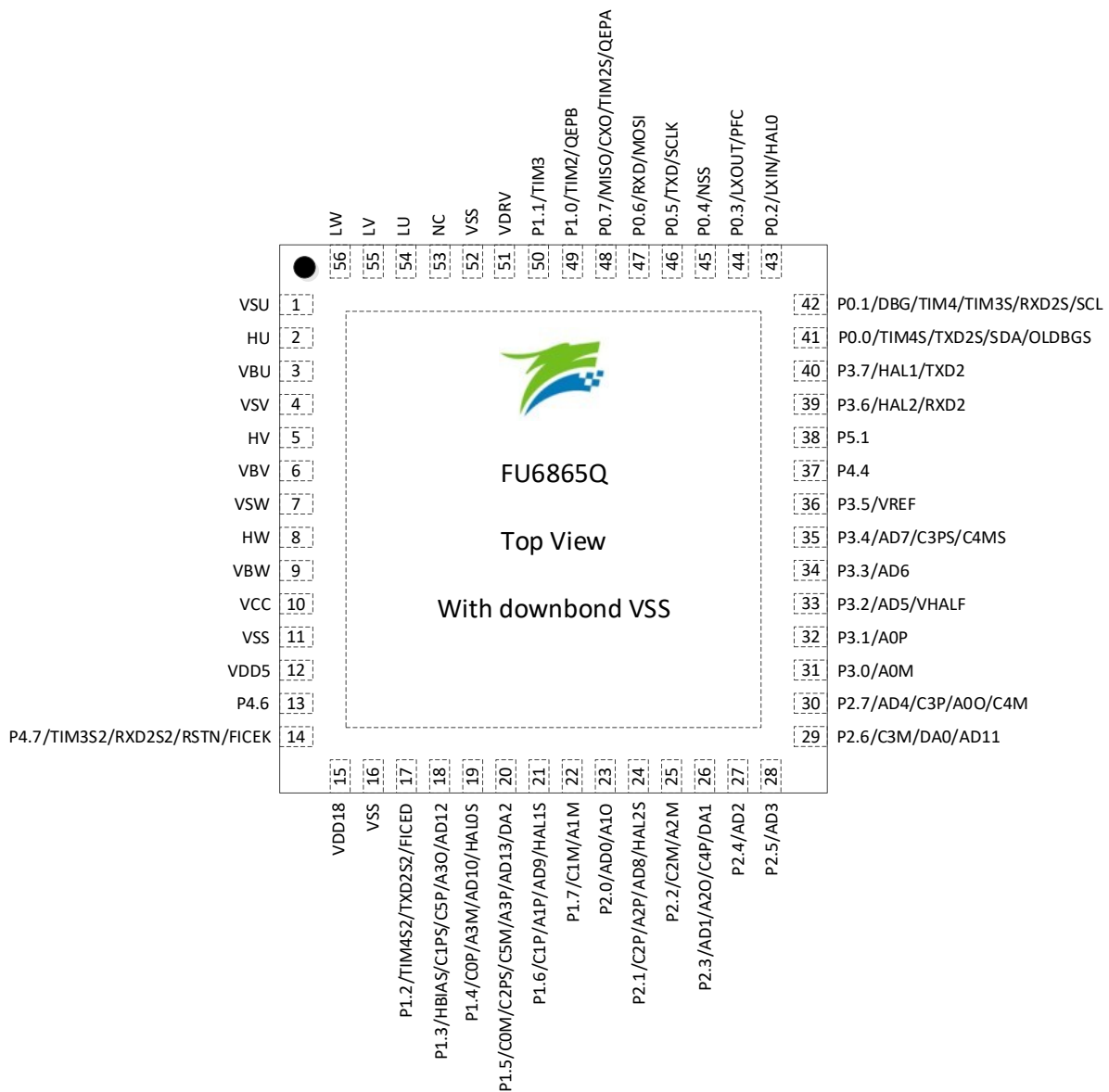


Figure 2-3 FU6865Q QFN56 Pinout Diagram

2.7 FU6864Q QFN48-38 Pins

Table 2-4 FU6864Q QFN48-38 Pin Descriptions

Pin	FU6864Q QFN48-38	IO Type	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 a 1μF ~ 4.7μF external capacitor
P0.0/ TIM4S/ TXD2S/ SDA/ OLDBGS	11	DO/ DB/ DO/ DO/ DO	GPIO, configurable as INT0 input Timer4 input/output after function switching UART2 TXD output after function switching I ² C SDA, configured as collector open-drain output SPI 1-wire debug output after function switching
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 ² 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

Pin	FU6864Q QFN48-38	IO Type	Description
HU	20	DO	6N pre-driver high-side U-phase PWM output
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
VSU	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 above. ■ Single-power supply mode: When VCC_MODE = 0, external power supply 12V~20V is connected to VCC pin, and internal LDO supplies VDD5 voltage.
VSS	29	P	Ground
VDD5	30	P	Internal LDO outputs 5V power supply, with an external capacitor of 1μF or above.
P4.7/ TIM3S2/ RXD2S2/ RSTN/ FICEK	31	DI/ DI/ DB/ DI/ DI	GPIO, used as an input only and configured with pull-up/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

2.8 FU6864Q QFN48-38 Pinout Diagram

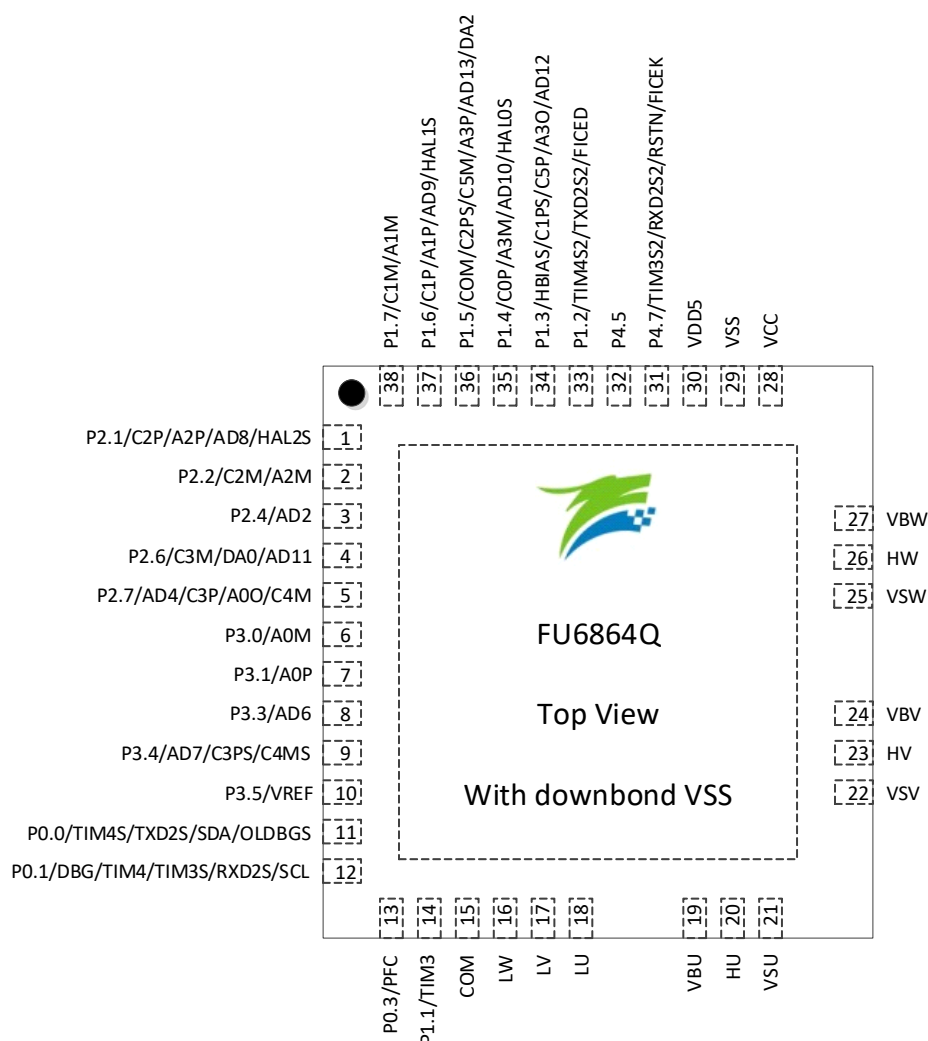


Figure 2-4 FU6864Q QFN48-38 Pinout Diagram

2.9 FU6864L LQFP52 Pins

Table 2-5 FU6864L LQFP52 Pin Descriptions

Pin	FU6864L LQFP52	IO Type	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 a 1μF external 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 a 1μF ~ 4.7μF external capacitor
P0.0/ TIM4S/ TXD2S/ SDA/ OLDBGS	11	DO/ DB/ DB/ DO/ DO	GPIO, configurable as INT0 input Timer4 input/output after function switching UART2 TXD output after function switching I ² C SDA, configured as collector open-drain output SPI 1-wire debug output after function switching
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 ² 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	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 4.7μF or larger. ■ Single-power supply mode: When VCC_MODE = 0, external power supply 12V~20V is connected to VCC pin, and internal LDO supplies VDD5 voltage.
VSS	41	P	Ground
VDD5	42	P	Internal LDO outputs 5V power supply, with an external capacitor of 1μF or above Power input or 5V internal LDO output, which is determined by VCC_MODE, with an external filter capacitor of 1μF 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	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

2.10 FU6864L LQFP52 Pinout Diagram

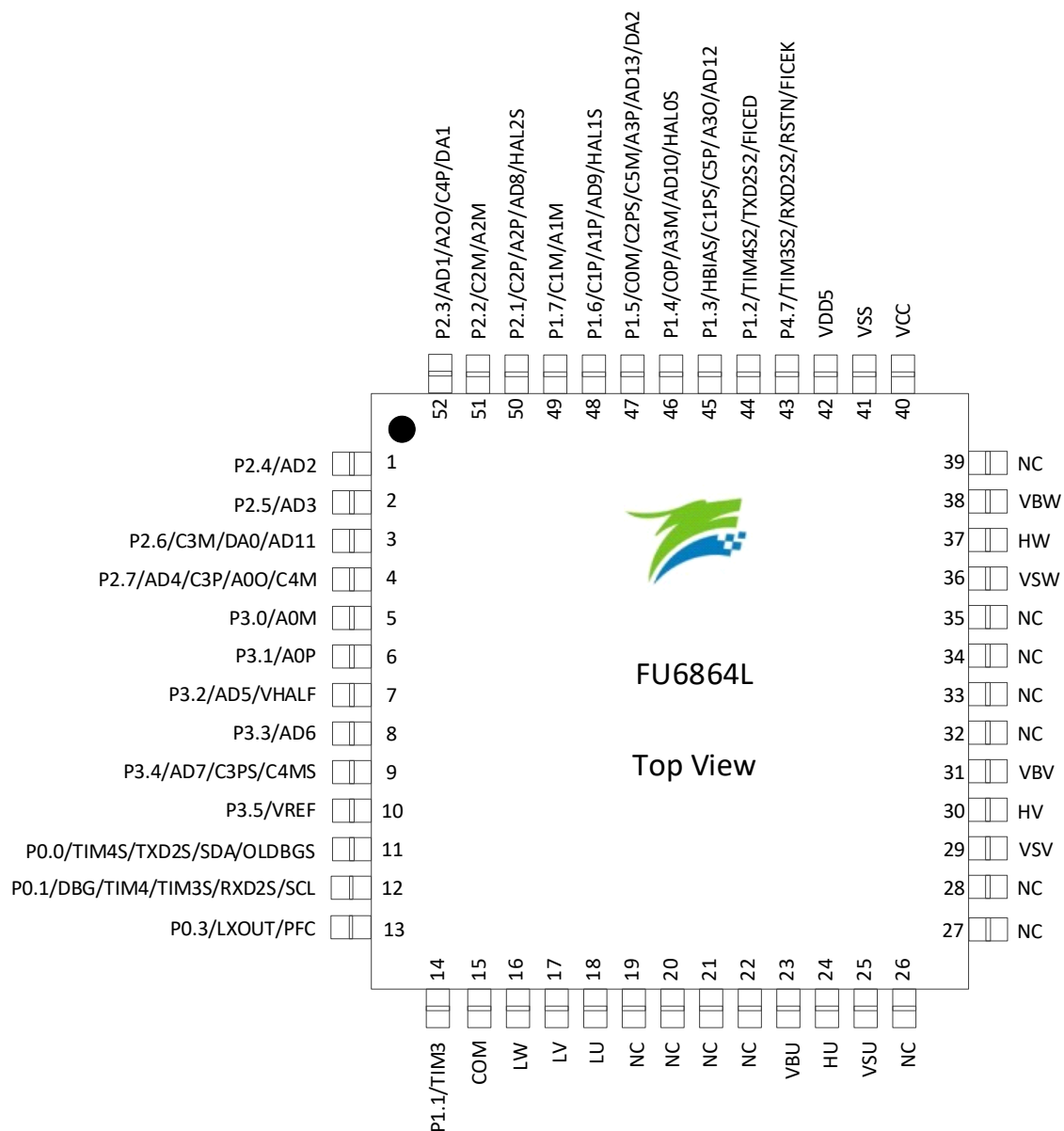


Figure 2-5 FU6864L LQFP52 Pinout Diagram

3 Package Information

3.1 LQFP48_7X7 (FU6815L)

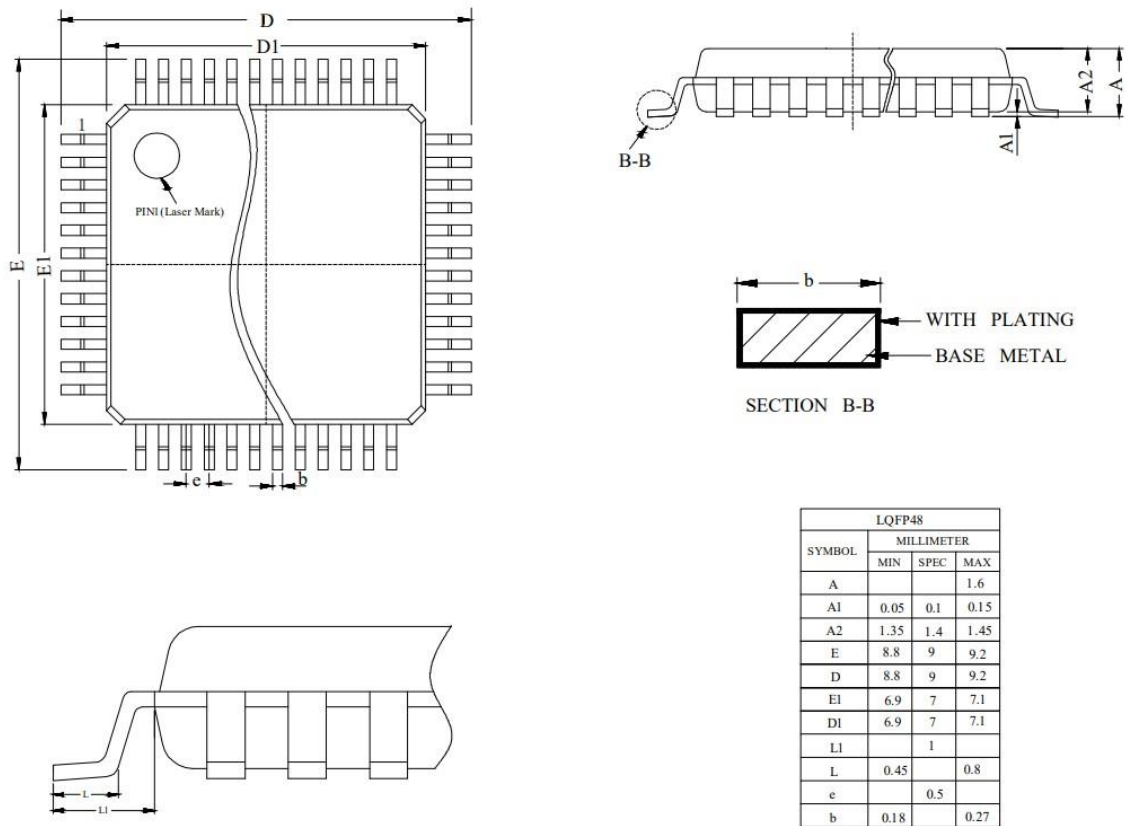


Figure 3-1 LQFP48_7X7 Package Drawings and Dimensions

3.2 TSSOP28 9.7X4.4 (FU6815T)

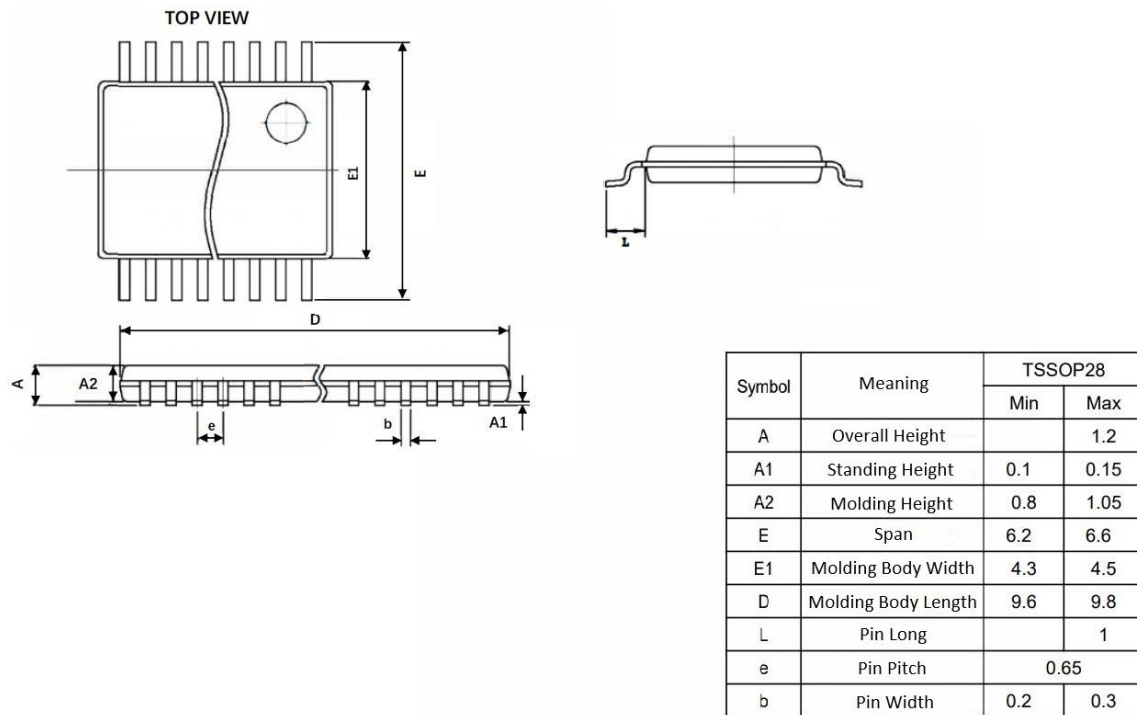


Figure 3-2 TSSOP28 9.7X4.4 Package Drawings and Dimensions

3.3 QFN56_7X7 (FU6865Q)

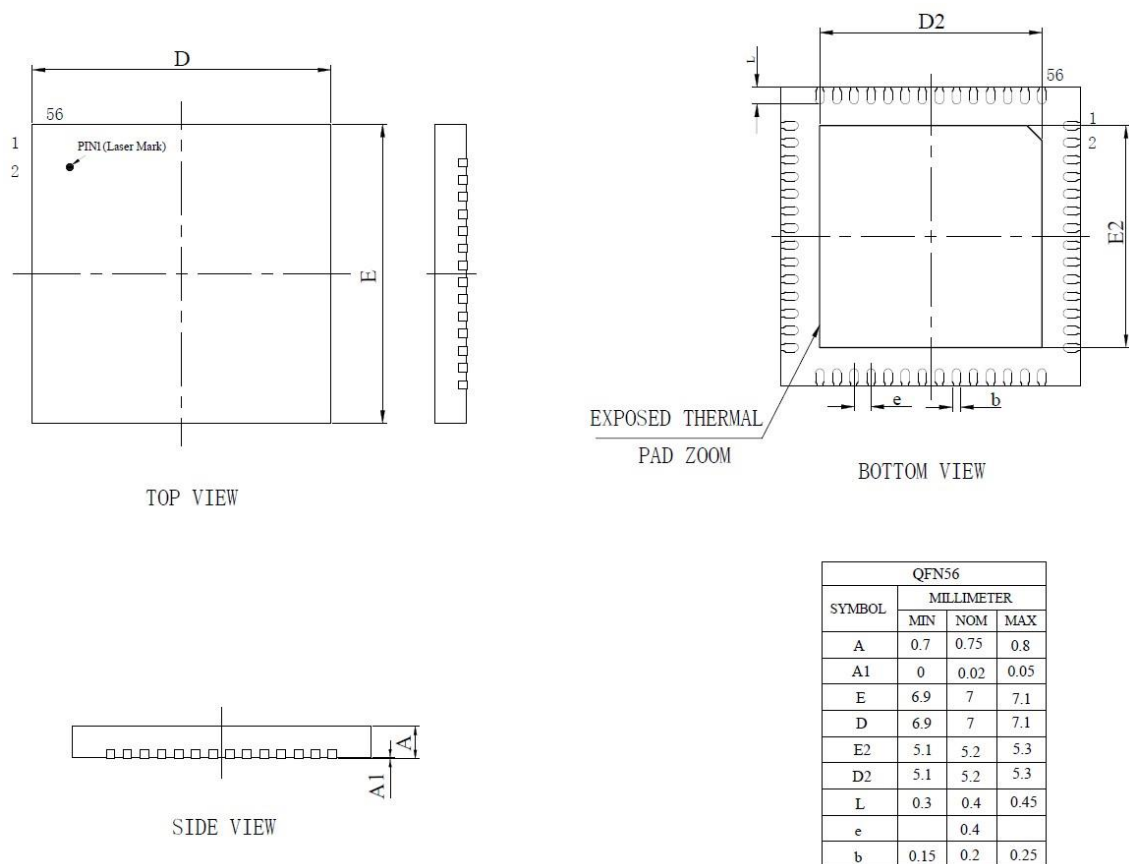


Figure 3-3 QFN56_7X7 Package Drawings and Dimensions

3.4 QFN48-38_7X7 (FU6864Q)

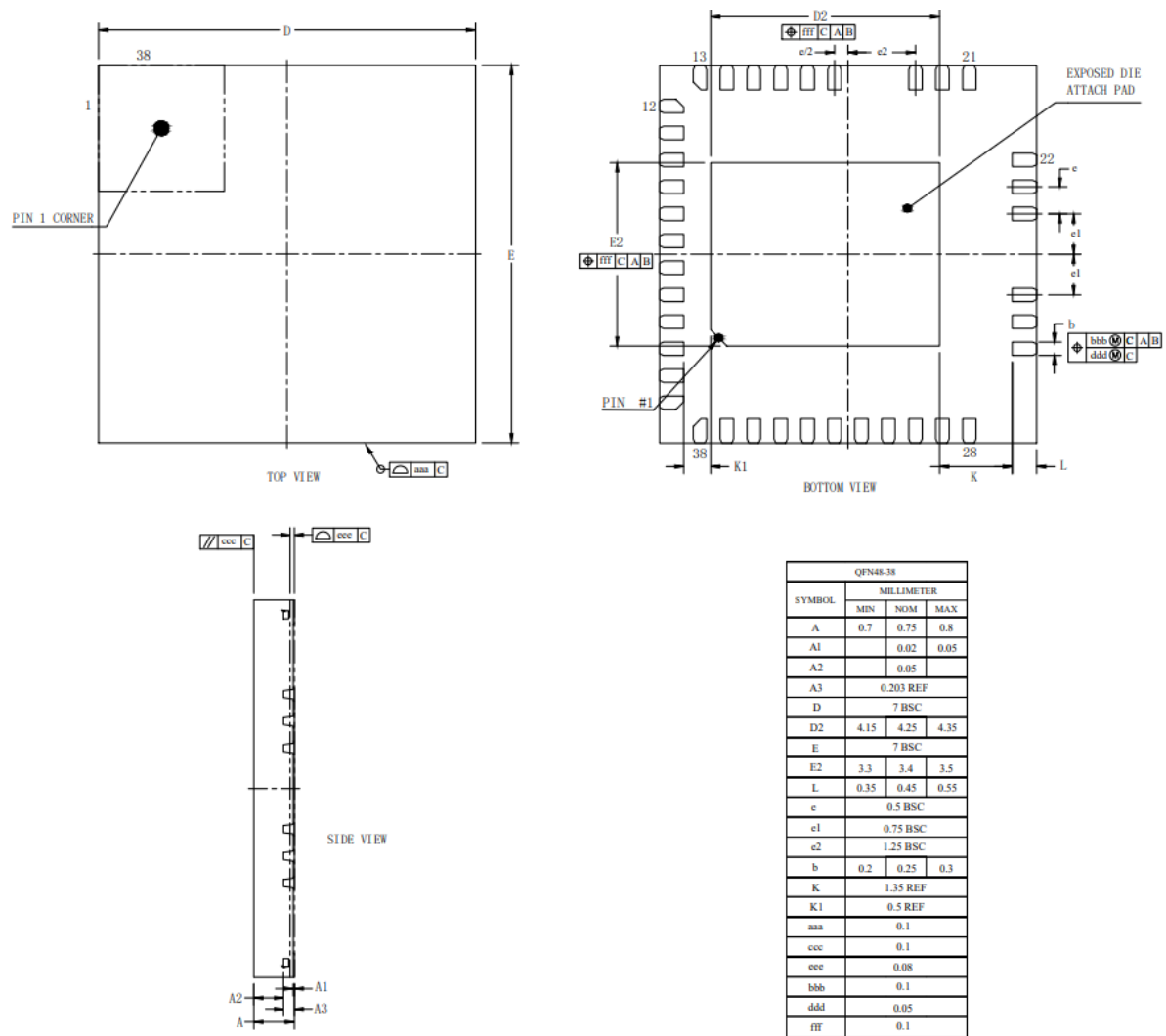


Figure 3-4 QFN48-38_7X7 Package Drawings and Dimensions

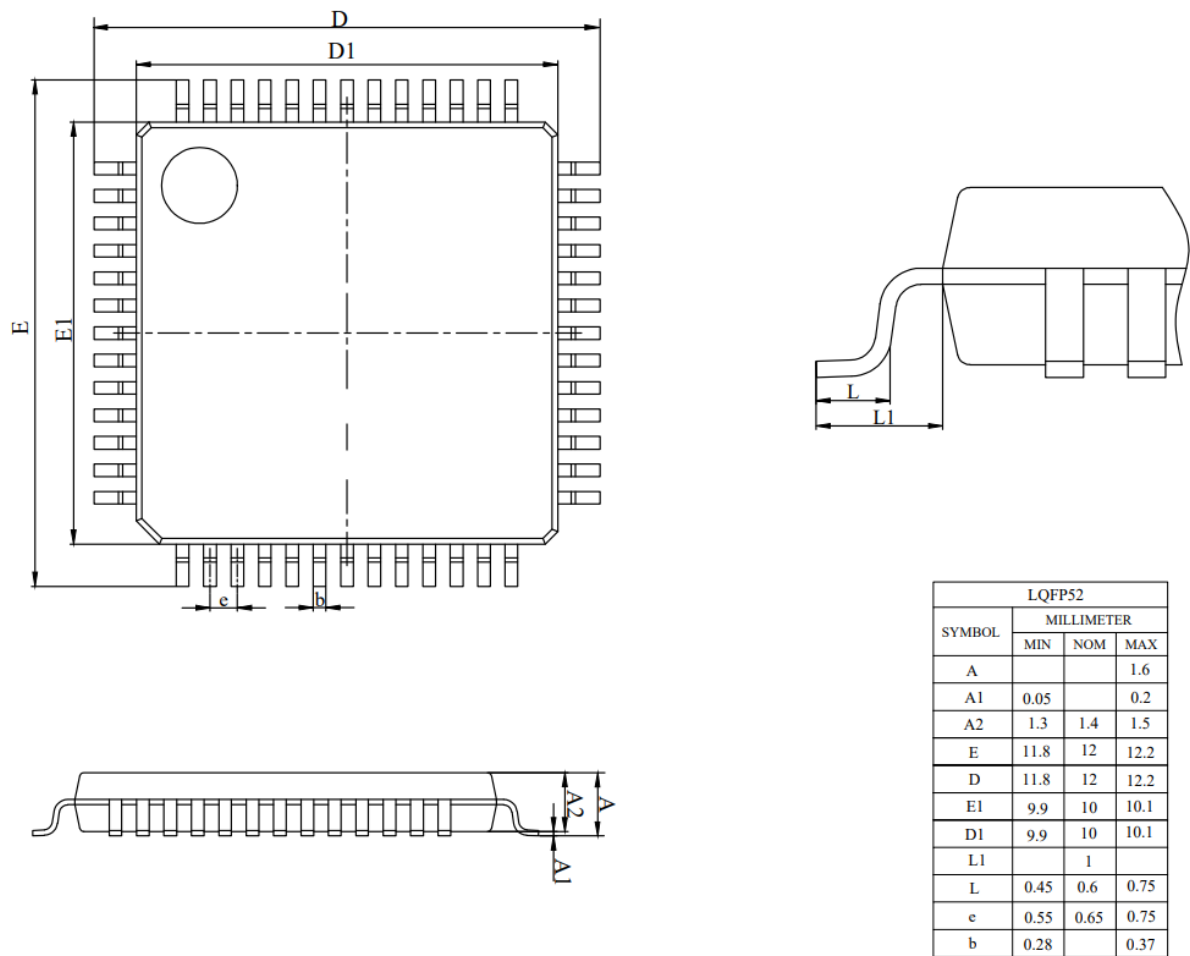
3.5 LQFP52_10X10 (FU6864L)


Figure 3-5 LQFP52_10X10 Package Drawings and Dimensions

4 Ordering Information

Table 4-1 Model Selections

Model	Clock Frequency (MHz)	Flash (kByte)	XRAM (kByte)	Clock Circuit			Driver Interface		Driver Type		I ² 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)
FU6815T	24	32	3.75	√	√	-	-	√	√	√	I ² C/UART	√	19	6	1	12	12	3	9\8\6	√	4	4	√	TSSOP28 (9.7x4.4mm)
FU6865Q	24	32	3.75	√	√	√	√	-	√	√	√	√	36	6	1	14	12	3	9\8\6	√	4	4	√	QFN56 (7x7mm)
FU6864Q	24	32	3.75	√	√	-	√	-	√	√	I ² C/UART	√	22	6	1	12	12	3	9\8\6	√	4	4	√	QFN48-38 (7x7mm)
FU6864L	24	32	3.75	√	√	-	√	-	√	√	I ² 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 Absolute Maximum Ratings for FU6815L

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 FU6815T

Table 5-2 Absolute Maximum Ratings for FU6815T

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

5.1.3 FU6865Q

Table 5-3 Absolute Maximum Ratings for FU6865Q

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
High-side Floating Voltage $V_{BU, BV, BW}$		-0.3	-	165	V
High-side Floating Voltage $V_{SU, SV, SW}$		$V_{BU, BV, BW} - 22$	-	$V_{BU, BV, BW} + 0.3$	V
High-side Floating Offset Voltage $V_{HU, HV, HW}$		$V_{SU, SV, SW} - 0.3$	-	$V_{BU, BV, BW} + 0.3$	V
Low-side Output Voltage $V_{LU, LV, LW}$		-0.3	-	VDRV + 0.3	V

5.1.4 FU6864Q

Table 5-4 Absolute Maximum Ratings for FU6864Q

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

5.1.5 FU6864L

Table 5-5 Absolute Maximum Ratings for FU6864L

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 5-6 Global Electrical Characteristics of FU6815L

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

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VCC Operating Voltage ^[1]	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 ^[2] , 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 ^[2]	3	-	5.5	V
I _{VCC} Operating Current ^[3]		-	15	-	mA
I _{VCC} Standby Current ^[3]		-	6	-	mA
I _{VCC} Sleep-mode Current	VCC = 12V	-	50	150	μA
Operating Ambient Temperature T_A		-40	-	85	°C
Operating Ambient Temperature T_A	$VCC \leq 15V$ & $I_{VCC} \leq 30mA$	-	-	105 ^[4]	°C

5.2.2 FU6815T

Table 5-7 Global Electrical Characteristics of FU6815T

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VCC Operating Voltage ^[1]	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 ^[2] , $VCC\_MODE = 1$, $VCC \geq VDD5$ 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 ^[2]	3	-	5.5	V
I _{VCC} Operating Current ^[3]		-	15	-	mA
I _{VCC} Standby Current ^[3]		-	6	-	mA
I _{VCC} Sleep-mode Current	VCC = 12V	-	50	150	μA
Operating Ambient Temperature T_A		-40	-	85	°C
Operating Ambient Temperature T_A	$VCC \leq 15V$ & $I_{vcc} \leq 30mA$	-	-	105 ^[4]	°C

5.2.3 FU6865Q

Table 5-8 Global Electrical Characteristics of FU6865Q

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

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VCC Operating Voltage ^[1]	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 ^[2] , $VCC\_MODE = 1$, $VCC \geq VDD5$ 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 ^[2]	3	-	5.5	V
I _{VCC} Operating Current ^[3]		-	20	-	mA
I _{VCC} Standby Current ^[3]		-	7	-	mA
I _{VCC} Sleep-mode Current		-	850	1650	μA
Operating Ambient Temperature T_A		-40	-	85	°C
Operating Ambient Temperature T_A	$VCC \leq 15V$ & $I_{vcc} \leq 30mA$	-	-	105 ^[4]	°C

5.2.4 FU6864Q

Table 5-9 Global Electrical Characteristics of FU6864Q

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

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VCC Operating Voltage ^[1]		12	-	20	V
V _{BU} , V _{BV} , V _{BW} Floating Voltage		-	-	600	V
V _{BU} , V _{BV} , V _{BW} to V _{SU} , V _{SV} , V _{SW} Voltage		-	-	18	V
I _{VCC} Operating Current ^[3]		-	24	-	mA
I _{VCC} Standby Current ^[3]		-	6	-	mA
I _{VCC} Sleep-mode Current	VCC = 12V	-	210	-	μA
Operating Ambient Temperature T_A		-40	-	85	°C
Operating Ambient Temperature T_A	$VCC \leq 15V$ & $I_{vcc} \leq 30mA$	-	-	105 ^[4]	°C

5.2.5 FU6864L

Table 5-10 Global Electrical Characteristics of FU6864L

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

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VCC Operating Voltage ^[1]		12	-	20	V
V _{BU} , V _{BV} , V _{BW} Floating Voltage		-	-	600	V
V _{BU} , V _{BV} , V _{BW} to V _{SU} , V _{SV} , V _{SW} Voltage		-	-	18	V
I _{VCC} Operating Current ^[3]		-	24	-	mA
I _{VCC} Standby Current ^[3]		-	6	-	mA
I _{VCC} Sleep-mode Current	VCC = 12V	-	210	-	μA
Operating Ambient Temperature T _A		-40	-	85	°C
Operating Ambient Temperature T _A	VCC ≤ 15V & I _{vcc} ≤ 30mA	-	-	105 ^[4]	°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.

[4] The chip can work at the maximum T_A only if T_J does not exceed the maximum T_J at any time.

5.3 GPIO Electrical Characteristics

5.3.1 FU6815L

Table 5-11 GPIO Electrical Characteristics of FU6815L

($T_A = 25^\circ\text{C}$ 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°C	-	15	-	ns
Output Fall Time	50pF load, from 90% to 10%, T _A = 25°C	-	13	-	ns
V _{OH} High-level Output Voltage	I _{OH} = 4mA, T _A = -40°C ~ 85°C	VDD5 - 0.7	-	-	V
V _{OL} Low-level Output Voltage	I _{OL} = 4mA, T _A = -40°C ~ 85°C	-	-	VSS + 0.7	V
V _{IH} High-level Input Voltage ^[1]		0.7*VDD5	-	-	V
V _{IL} Low-level Input Voltage		-	-	0.2*VDD5	V
Pull-up Resistor ^[2]		-	33	-	kΩ
Pull-up Resistor ^[3]		-	5.6	-	kΩ
Pull-down Resistor ^[4]		-	30	-	kΩ

Notes:

[1] When VDD5 = 5V, the minimum value of V_{IH} is 0.6*VDD5.

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

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

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

5.3.2 FU6815T

Table 5-12 GPIO Electrical Characteristics of FU6815T

(T_A = 25°C and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Output Rise Time	50pF load, from 10% to 90%, T _A = 25°C	-	15	-	ns
Output Fall Time	50pF load, from 90% to 10%, T _A = 25°C	-	13	-	ns
V _{OH} High-level Output Voltage	I _{OH} = 4mA, T _A = -40°C~85°C	VDD5 - 0.7	-	-	V
V _{OL} Low-level Output Voltage	I _{OL} = 4mA, T _A = -40°C~85°C	-	-	VSS + 0.7	V
V _{IH} High-level Input Voltage ^[1]		0.7*VDD5	-	-	V
V _{IL} Low-level Input Voltage		-	-	0.2*VDD5	V
Pull-up Resistor ^[2]		-	33	-	kΩ
Pull-up Resistor ^[3]		-	5.6	-	kΩ
Pull-down Resistor ^[4]		-	30	-	kΩ

Notes:

[1] When VDD5 = 5V, the minimum value of V_{IH} is 0.6*VDD5.

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

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

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

5.3.3 FU6865Q

Table 5-13 GPIO Electrical Characteristics of FU6865Q

(T_A = 25°C and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Output Rise Time	50pF load, from 10% to 90%, T _A = 25°C	-	15	-	ns
Output Fall Time	50pF load, from 90% to 10%, T _A = 25°C	-	13	-	ns
V _{OH} High-level Output Voltage	I _{OH} = 4mA, T _A = -40°C~85°C	VDD5 - 0.7	-	-	V
V _{OL} Low-level Output Voltage	I _{OL} = 4mA, T _A = -40°C~85°C	-	-	VSS + 0.7	V
V _{IH} High-level Input Voltage ^[1]		0.7*VDD5	-	-	V
V _{IL} Low-level Input Voltage		-	-	0.2*VDD5	V
Pull-up Resistor ^[2]		-	33	-	kΩ
Pull-up Resistor ^[3]		-	5.6	-	kΩ
Pull-down Resistor ^[4]		-	30	-	kΩ

Notes:

[1] When VDD5 = 5V, the minimum value of V_{IH} is 0.6*VDD5.

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

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

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

5.3.4 FU6864Q

Table 5-14 GPIO Electrical Characteristics of FU6864Q

($T_A = 25^\circ\text{C}$ 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} High-level Output Voltage	$I_{OH} = 4\text{mA}$, $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	$V_{DD5} - 0.7$	-	-	V
V_{OL} Low-level Output Voltage	$I_{OL} = 4\text{mA}$, $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	-	-	$V_{SS} + 0.7$	V
V_{IH} High-level Input Voltage ^[1]		$0.7 \cdot V_{DD5}$	-	-	V
V_{IL} Low-level Input Voltage		-	-	$0.2 \cdot V_{DD5}$	V
Pull-up Resistor ^[2]	$V_{DD5} = 5\text{V}$	-	33	-	k Ω
Pull-up Resistor ^[3]	$V_{DD5} = 5\text{V}$	-	5.6	-	k Ω
Pull-down Resistor ^[4]	$V_{DD5} = 5\text{V}$	-	30	-	k Ω

Notes:

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

[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].

5.3.5 FU6864L

Table 5-15 GPIO Electrical Characteristics of FU6864L

($T_A = 25^\circ\text{C}$ 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} High-level Output Voltage	$I_{OH} = 4\text{mA}$, $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	$V_{DD5} - 0.7$	-	-	V
V_{OL} Low-level Output Voltage	$I_{OL} = 4\text{mA}$, $T_A = -40^\circ\text{C} \sim 85^\circ\text{C}$	-	-	$V_{SS} + 0.7$	V
V_{IH} High-level Input Voltage ^[1]		$0.7 \cdot V_{DD5}$	-	-	V
V_{IL} Low-level Input Voltage		-	-	$0.2 \cdot V_{DD5}$	V
Pull-up Resistor ^[2]	$V_{DD5} = 5\text{V}$	-	33	-	k Ω
Pull-up Resistor ^[3]	$V_{DD5} = 5\text{V}$	-	5.6	-	k Ω
Pull-down Resistor ^[4]	$V_{DD5} = 5\text{V}$	-	30	-	k Ω

Notes:

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

[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/FU6815T)

5.4.1 FU6815L

Table 5-16 PWM IO Electrical Characteristics of FU6815L

(T_A = 25°C, VCC = 15V and VCC_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°C	-	18	-	ns
Output Fall Time	50pF load, from 90% to 10%, T _A = 25°C	-	12	-	ns

5.4.2 FU6815T

Table 5-17 PWM IO Electrical Characteristics of FU6815T

(T_A = 25°C, VCC = 15V and VCC_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°C	-	18	-	ns
Output Fall Time	50pF load, from 90% to 10%, T _A = 25°C	-	12	-	ns

5.5 6N Pre-driver IO Electrical Characteristics (FU6865Q/FU6864Q/FU6864L)

5.5.1 FU6865Q

Table 5-18 6N Pre-driver IO Electrical Characteristics of FU6865Q

(T_A = 25°C, VCC = VDRV = 15V and VCC_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 Release 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 5-19 6N Pre-driver IO Electrical Characteristics of FU6864Q

(T_A = 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
High-side Floating Voltage V _{BU, BV, BW}		-	-	600	V
High-side Floating Offset Voltage V _{SU, SV, SW}		V _{BU, BV, BW} - 20	-	V _{BU, BV, BW} - 12	V
VCC Quiescent Current		-	0.14	-	mA
VCC UVLO Threshold Voltage		8.1	9.0	9.9	V
VCC UVLO Release 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 5-20 6N Pre-driver IO Electrical Characteristics of FU6864L

(T_A = 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
High-side Floating Voltage V _{BU, BV, BW}		-	-	600	V
High-side Floating Offset Voltage V _{SU, SV, SW}		V _{BU, BV, BW} - 20	-	V _{BU, BV, BW} - 12	V
VCC Quiescent Current		-	0.14	-	mA
VCC UVLO Threshold Voltage		8.1	9.0	9.9	V
VCC UVLO Release 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 5-21 ADC Electrical Characteristics of FU6815L

(T_A = 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 _{IN} = 350kHz	-	70.8	-	dB
ENOB (Effective Number of Bits)	f _{IN} = 350kHz	-	10.5	-	Bit
SFDR (Spurious-free Dynamic Range)	f _{IN} = 350kHz	-	68.2	-	dB
THD (Total Harmonic Distortion)	f _{IN} = 350kHz	-	67	-	dB
R _{IN} Input Resistance		-	800	-	Ω
C _{IN} Input Capacitance		-	30	-	pF
Conversion Time		-	13	-	ADCLK ^[1]
Sampling Time		3	-	63	ADCLK2 ^[2]

5.6.2 FU6815T

Table 5-22 ADC Electrical Characteristics of FU6815T

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} = 350kHz	-	70.8	-	dB
ENOB (Effective Number of Bits)	f _{IN} = 350kHz	-	10.5	-	Bit
SFDR (Spurious-free Dynamic Range)	f _{IN} = 350kHz	-	68.2	-	dB
THD (Total Harmonic Distortion)	f _{IN} = 350kHz	-	67	-	dB
R _{IN} Input Resistance		-	800	-	Ω
C _{IN} Input Capacitance		-	30	-	pF
Conversion Time		-	13	-	ADCLK ^[1]
Sampling Time		3	-	63	ADCLK2 ^[2]

5.6.3 FU6865Q

Table 5-23 ADC Electrical Characteristics of FU6865Q

(T_A = 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 _{IN} = 350kHz	-	70.8	-	dB
ENOB (Effective Number of Bits)	f _{IN} = 350kHz	-	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	-	Ω
C_{IN} Input Capacitance		-	30	-	pF
Conversion Time		-	13	-	ADCLK ^[1]
Sampling Time		3	-	63	ADCLK2 ^[2]

5.6.4 FU6864Q

Table 5-24 ADC Electrical Characteristics of FU6864Q

($T_A = 25^\circ\text{C}$ 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	-	Ω
C_{IN} Input Capacitance		-	30	-	pF
Conversion Time		-	13	-	ADCLK ^[1]
Sampling Time		3	-	63	ADCLK2 ^[2]

5.6.5 FU6864L

Table 5-25 ADC Electrical Characteristics of FU6864L

($T_A = 25^\circ\text{C}$ 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	-	Ω
C_{IN} Input Capacitance		-	30	-	pF
Conversion Time		-	13	-	ADCLK ^[1]
Sampling Time		3	-	63	ADCLK ^[1]

Notes:

[1] ADCLK = 24MHz

[2] ADCLK2 = 12MHz

5.7 VREF and VHALF Electrical Characteristics

5.7.1 FU6815L

Table 5-26 VREF and VHALF Electrical Characteristics of FU6815L

(T_A = -40°C ~ 85°C and VCC = 5V ~ 28V)

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

5.7.2 FU6815T

Table 5-27 VREF and VHALF Electrical Characteristics of FU6815T

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

5.7.3 FU6865Q

Table 5-28 VREF and VHALF Electrical Characteristics of FU6865Q

(T_A = -40°C ~ 85°C and VCC = 5V ~ 28V)

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

5.7.4 FU6864Q

Table 5-29 VREF and VHALF Electrical Characteristics of FU6864Q

(T_A = -40°C ~ 85°C and VCC = 12V ~ 20V)

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

5.7.5 FU6864L

Table 5-30 VREF and VHALF Electrical Characteristics of FU6864L

(T_A = -40°C ~ 85°C and VCC = 12V ~ 20V)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VREF	VREF_VHALF_CR[VREFVSEL] = 00	4.3	4.5	4.7	V
	VREF_VHALF_CR[VREFVSEL] = 01	-	VDD5	-	V
	VREF_VHALF_CR[VREFVSEL] = 11	-	4	-	V
	VREF_VHALF_CR[VREFVSEL] = 10	-	3	-	V
VHALF	VREF_VHALF_CR[VHALFSEL] = 00	-	VREF/8	-	V
	VREF_VHALF_CR[VHALFSEL] = 01	-	VREF/4	-	V
	VREF_VHALF_CR[VHALFSEL] = 10	-	25*VREF/64	-	V
	VREF_VHALF_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 5-31 Operational Amplifier Electrical Characteristics of FU6815L

(T_A = 25°C and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V _{ICMR} Common-mode Input Voltage Range		0	-	VDD5 - 1.5	V
V _{OS} Operational Amplifier Offset Voltage	T _A = 25°C	-	5	10	mV
A _{OL} Open-loop Gain	R _L = 100kΩ	-	80	-	dB
Unity-gain Bandwidth (UGBW)	C _L = 40pF	6	10	-	MHz
Slew Rate (SR)	C _L = 40pF	10	15	-	V/μs
Operational Amplifier Gain ^{[1][2]}	AMP_CR1[AMP0_GAIN] = 001	1.88	2	2.12	-
	AMP_CR1[AMP0_GAIN] = 010	3.76	4	4.24	-

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
	AMP_CR1[AMP0_GAIN] = 011	7.5	8	8.5	-
	AMP_CR1[AMP0_GAIN] = 100	15	16	17	-

5.8.2 FU6815T

Table 5-32 Operational Amplifier Electrical Characteristics of FU6815T

(T_A = 25°C and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V _{ICMR} Common-mode Input Voltage Range		0	-	VDD5 - 1.5	V
V _{OS} Operational Amplifier Offset Voltage	T _A = 25°C	-	5	10	mV
A _{OL} Open-loop Gain	R _L = 100kΩ	-	80	-	dB
Unity-gain Bandwidth (UGBW)	C _L = 40pF	6	10	-	MHz
Slew Rate (SR)	C _L = 40pF	10	15	-	V/μs
Operational Amplifier Gain ^{[1][2]}	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 FU6865Q

Table 5-33 Operational Amplifier Electrical Characteristics of FU6865Q

(T_A = 25°C and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V _{ICMR} Common-mode Input Voltage Range		0	-	VDD5 - 1.5	V
V _{OS} Operational Amplifier Offset Voltage	T _A = 25°C	-	5	10	mV
A _{OL} Open-loop Gain	R _L = 100kΩ	-	80	-	dB
Unity-gain Bandwidth (UGBW)	C _L = 40pF	6	10	-	MHz
Slew Rate (SR)	C _L = 40pF	10	15	-	V/μs
Operational Amplifier Gain ^[1]	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 FU6864Q

Table 5-34 Operational Amplifier Electrical Characteristics of FU6864Q

(T_A = 25°C and VCC = 12V ~ 20V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V _{ICMR} Common-mode Input Voltage Range		0	-	VDD5 - 1.5	V
V _{OS} Operational Amplifier Offset Voltage	T _A = 25°C	-	5	-	mV

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
A _{OL} Open-loop Gain	R _L = 100kΩ	-	80	-	dB
Unity-gain Bandwidth (UGBW)	C _L = 40pF	6	10	-	MHz
Slew Rate (SR)	C _L = 40pF	10	15	-	V/μs
Operational Amplifier Gain ^{[1][2]}	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	-

5.8.5 FU6864L

Table 5-35 Operational Amplifier Electrical Characteristics of FU6864L

(T_A = 25°C and VCC = 12V ~ 20V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V _{ICMR} Common-mode Input Voltage Range		0	-	VDD5 - 1.5	V
V _{OS} Operational Amplifier Offset Voltage	T _A = 25°C	-	5	-	mV
A _{OL} Open-loop Gain	R _L = 100kΩ	-	80	-	dB
Unity-gain Bandwidth (UGBW)	C _L = 40pF	6	10	-	MHz
Slew Rate (SR)	C _L = 40pF	10	15	-	V/μs
Operational Amplifier Gain ^{[1][2]}	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	-

Notes:

[1] The operational amplifier gain is measured when both positive and negative inputs of the operational amplifier are connected in series with 1kΩ resistors. The operational amplifier gain varies with external resistors.

[2] AMP0 is used as an example. See AMP_CR1 (0x4034) for configurations of other operational amplifiers.

5.9 BEMF Electrical Characteristics

5.9.1 FU6815L

Table 5-36 BEMF Electrical Characteristics of FU6815L

(T_A = 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	kΩ
Relative Accuracy between BEMF Built-in Resistors		-	1	-	%

5.9.2 FU6815T

Table 5-37 BEMF Electrical Characteristics of FU6815T

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

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

5.9.3 FU6865Q

Table 5-38 BEMF Electrical Characteristics of FU6865Q

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

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

5.9.4 FU6864Q

Table 5-39 BEMF Electrical Characteristics of FU6864Q

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

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

5.9.5 FU6864L

Table 5-40 BEMF Electrical Characteristics of FU6864L

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

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

5.10 OSC Electrical Characteristics

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

5.10.1 FU6815L

Table 5-41 OSC Electrical Characteristics of FU6815L

($T_A = -40^{\circ}\text{C} \sim 85^{\circ}\text{C}$, $V_{CC\_MODE} = 0$ 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 FU6815T

Table 5-42 OSC Electrical Characteristics of FU6815T

($T_A = -40^{\circ}\text{C} \sim 85^{\circ}\text{C}$, $V_{CC\_MODE} = 0$ 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 FU6865Q

Table 5-43 OSC Electrical Characteristics of FU6865Q

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

5.10.4 FU6864Q

Table 5-44 OSC Electrical Characteristics of FU6864Q

($T_A = -40^{\circ}\text{C} \sim 85^{\circ}\text{C}$ 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

5.10.5 FU6864L

Table 5-45 OSC Electrical Characteristics of FU6864L

($T_A = -40^{\circ}\text{C} \sim 85^{\circ}\text{C}$ 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 5-46 Reset Electrical Characteristics of FU6815L

(T_A = 25°C, VCC_MODE = 0 and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Minimum Time for RSTN Released to Low		50	-	-	μs
VDD5 Reset Threshold	Reset Voltage LVR = 3.0V	2.8	3.0	3.2	V

5.11.2 FU6815T

Table 5-47 Reset Electrical Characteristics of FU6815T

(T_A = 25°C, VCC_MODE = 0 and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Minimum Time for RSTN Released to Low		50	-	-	μs
VDD5 Reset Threshold	Reset Voltage LVR = 3.0V	2.8	3.0	3.2	V

5.11.3 FU6865Q

Table 5-48 Reset Electrical Characteristics of FU6865Q

(T_A = 25°C, VCC_MODE = 0 and VCC = 5V ~ 28V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Minimum Time for RSTN Released to Low		50	-	-	μs
VDD5 Reset Threshold	Reset Voltage LVR = 3.0V	2.8	3.0	3.2	V

5.11.4 FU6864Q

Table 5-49 Reset Electrical Characteristics of FU6864Q

(T_A = 25°C and VCC = 12V ~ 20V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Minimum Time for RSTN Released to Low		50	-	-	μs
VDD5 Reset Threshold	Reset Voltage LVR = 3.0V	2.8	3.0	3.2	V

5.11.5 FU6864L

Table 5-50 Reset Electrical Characteristics of FU6864L

(T_A = 25°C and VCC = 12V ~ 20V unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
Minimum Time for RSTN Released to Low		50	-	-	μs
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 5-51 LDO Electrical Characteristics of FU6815L

(T_A = 25°C, VCC = 5V ~ 28V and VCC_MODE = 0 unless otherwise specified)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
VDD5 Voltage	VCC = 7V ~ 28V and VCC_MODE = 0	4.7	5	5.3	V
VDD18 Voltage		1.65	1.85	2.0	V

5.12.2 FU6815T

Table 5-52 LDO Electrical Characteristics of FU6815T

($T_A = 25^\circ\text{C}$, $V_{CC} = 5\text{V} \sim 28\text{V}$ 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
VDD18 Voltage		1.65	1.85	2.0	V

5.12.3 FU6865Q

Table 5-53 LDO Electrical Characteristics of FU6865Q

($T_A = 25^\circ\text{C}$, $V_{CC} = 5\text{V} \sim 28\text{V}$ 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
VDD18 Voltage		1.65	1.85	2.0	V

5.12.4 FU6864Q

Table 5-54 LDO Electrical Characteristics of FU6864Q

($T_A = 25^\circ\text{C}$, $V_{CC} = 12\text{V} \sim 20\text{V}$ 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

5.12.5 FU6864L

Table 5-55 LDO Electrical Characteristics of FU6864L

($T_A = 25^\circ\text{C}$, $V_{CC} = 12\text{V} \sim 20\text{V}$ 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 5-56 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	$^\circ\text{C/W}$
	JEDEC standard, 1S0P PCB	72.2	$^\circ\text{C/W}$
Junction-to-case Temperature Thermal Resistance $\theta_{JC}^{[1]}$	JEDEC standard, 1S0P PCB	17	$^\circ\text{C/W}$

5.13.2 FU6815T TSSOP28

Table 5-57 FU6815T TSSOP28 Package Thermal Resistance

Parameter	Test Conditions	Value	Unit
Junction-to-ambient Temperature Thermal Resistance $\theta_{JA}^{[1]}$	JEDEC standard, 2S2P PCB	65	°C/W
	JEDEC standard, 1S0P PCB	85	°C/W
Junction-to-case Temperature Thermal Resistance $\theta_{JC}^{[1]}$	JEDEC standard, 2S2P PCB	20	°C/W

5.13.3 FU6865Q QFN56

Table 5-58 FU6865Q QFN56 Package Thermal Resistance

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

5.13.4 FU6864Q QFN48-38

Table 5-59 FU6864Q 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

5.13.5 FU6864L LQFP52

Table 5-60 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 (SOFTTR)

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 μ 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 VCC. When VCC 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 VCC 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]
I ² C 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	-	-
Reset	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 ² 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	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 Note: This flag is often used with the overtemperature status bit LVSR[TSDIF].
[4:3]	IT1	External Interrupt 1 (INT1) Edge Select 00: Interrupt on rising edge 01: Interrupt on falling edge 1X: Interrupt on edge changes (rise or fall)
[2]	IF0	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
[1:0]	IT0	External Interrupt 0 (INT0) Edge Select 00: Interrupt on rising edge 01: Interrupt on falling edge 1X: Interrupt on edge changes (rise or fall)

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 I²C

8.1 I²C Introduction

The I²C module provides an industry standard two-wire serial interface and is a simple bi-directional synchronous serial bus for communication between MCU and external I²C 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 I²C is enabled, P0.0 and P0.1 automatically shifts into open-drain outputs.

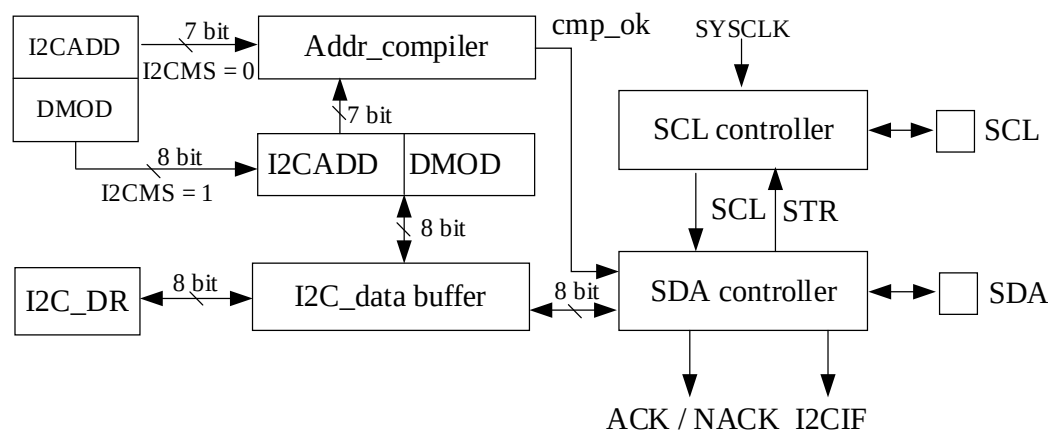


Figure 8-1 I²C Block Diagram

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 I²C 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.

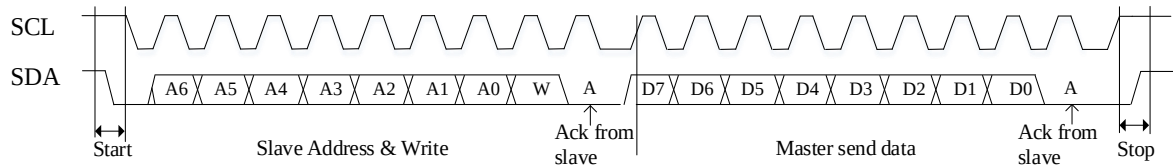


Figure 8-2 Master Transmits Data to Slave

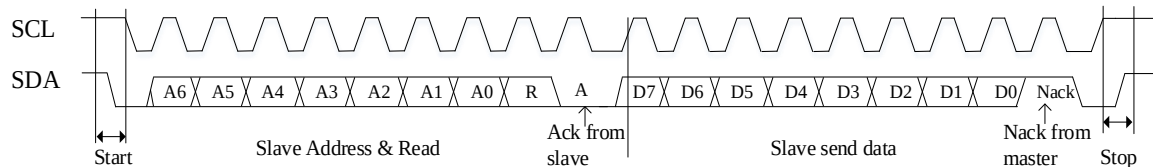


Figure 8-3 Master Receives Data from Slave

8.2 I²C 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 I²C;
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 I²C;
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 I²C Interrupt Sources

The interrupt sources of I²C 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 I²C 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 ² C Enable Enable the associated GPIO and switch to I ² C mode, serving as collector open-drain output. The pull-up setting decides whether to pull I ² C HIGH. 0: Disable 1: Enable
[6]	I2CMS	Master/Slave Mode Selection 0: Slave 1: Master
[5:3]	RSV	Reserved
[2:1]	I2CSPD	I ² C transfer rate setting, valid only in Master Mode 00: 100kHz 01: 400kHz 10: 1MHz 11: Reserved

[0]	I2CIE	I ² 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 ² 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	I²C 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	I²C 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	Master Mode: 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 Slave Mode: This bit is set to “1” after hardware receives START and address matches, and cleared to “0” by software. Table 8-1 Mapping of I2C_SR[I2CSTA] and I2C_SR[I2CSTP] in Slave Mode <table border="1"> <thead> <tr> <th>I2CSTA</th><th>I2CSTP</th><th>I²C 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> Note: When I2C_CR[I2CEN] = 0, I2C_SR[I2CSTA] is automatically cleared to “0”.	I2CSTA	I2CSTP	I ² 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 ² 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	Master Mode: 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”, I²C 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. Slave Mode: 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. Note: When I2C_CR[I2CEN] = 0, I2C_SR[I2CSTP] is automatically cleared to “0” by hardware.															
[2]	STR	I²C Bus Pending Flag Master Mode: 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 & address bytes. Slave Mode: 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. 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”.															
[1]	NACK	This bit refers to the feedback from a receiver to a sender after a byte is transferred via I²C. 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 8th bit of data is received.															

		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 th bit of data is transmitted. 0: Bit9 receives ACK 1: Bit9 receives NACK
[0]	I2CIF	I ² 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.

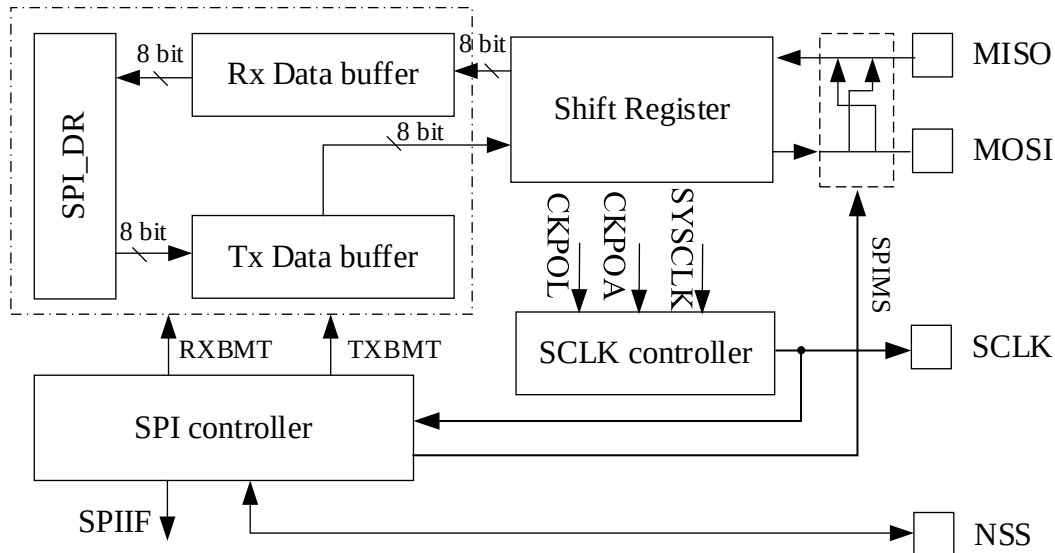


Figure 9-1 SPI Block Diagram

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.

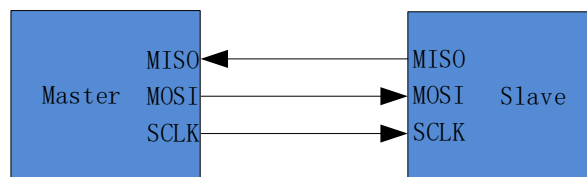


Figure 9-2 Connection Diagram of 3-Wire SPI Mode

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.

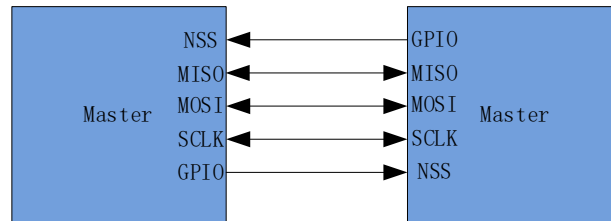


Figure 9-3 Connection Diagram of 4-Wire Multi-Master Mode

When $\text{SPI\_CR1}[\text{NSSMOD}] = 1\text{X}$, 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. $\text{SPI\_CR1}[\text{NSSMOD0}]$ 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.

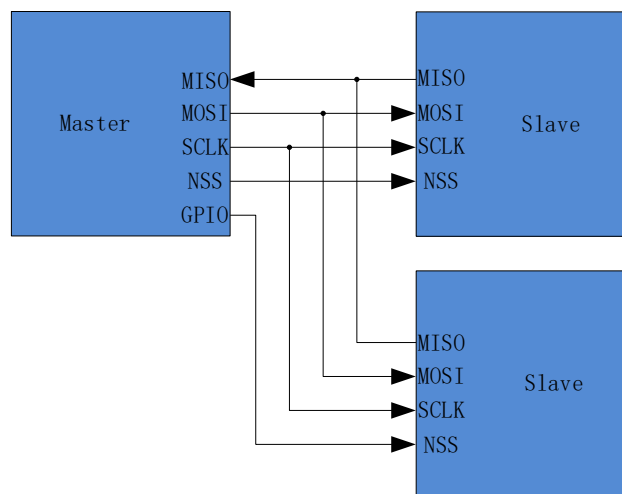


Figure 9-4 Connection Diagram of 4-Wire Single Master Mode

9.2.2 SPI Master Mode

When $\text{SPI\_CR0}[\text{SPIMS}] = 1$, 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 $\text{SPI\_CR1}[\text{TXBMT}]$ 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, $\text{SPI\_CR1}[\text{SPIIF}]$ and $\text{SPI\_CR1}[\text{TXBMT}]$ 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, $\text{SPI\_CR1}[\text{SPIIF}]$ 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 $\text{SPI\_CR1}[\text{TXBMT}]$ is “0”, the write conflict flag bit $\text{SPI\_CR1}[\text{WCOL}]$ 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.

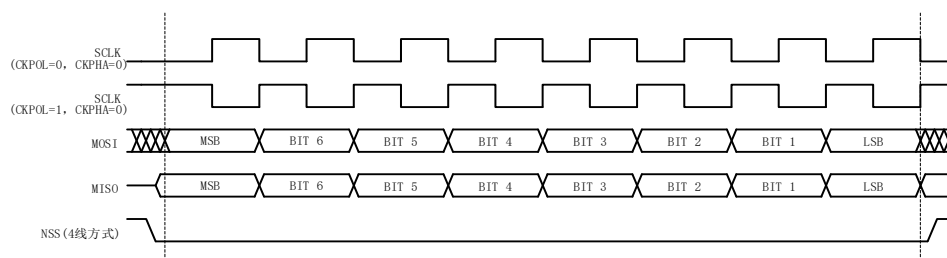


Figure 9-5 SDA/SCL Line Timing Diagram (SPI_CR0[CPHA] = 0)

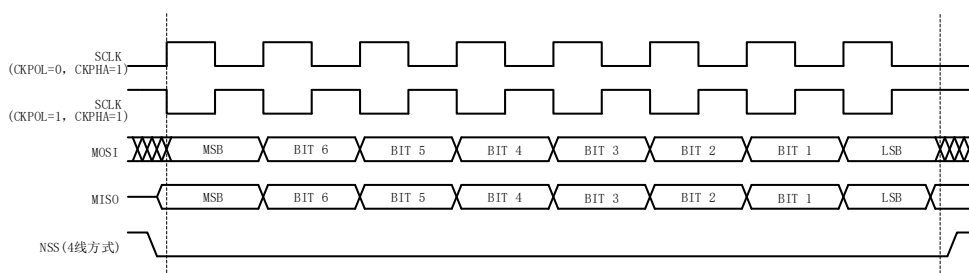


Figure 9-6 SDA/SCL Line Timing Diagram (SPI_CR0[CPHA] = 1)

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	SPI Interrupt Flag This bit is set to “1” by hardware each time after a data frame (8-bit) is transferred. Read: 0: No Interrupt Pending . 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: No effect.
[6]	WCOL	Write Conflict Interrupt Flag When SPI_CR1[TXBMT] is “0”, a write to SPI_DR sets this bit to 1. This bit can be cleared to “0” by software only. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: No effect.
[5]	MODF	Master Mode Fault Interrupt Flag 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). This bit can be cleared to “0” by software only. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: No effect.
[4]	RXOVRN	Receive Overflow Interrupt Flag (Slave Mode only) 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. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: No effect.
[3:2]	NSSMOD	SPI Mode Selection 00: 3-Wire Slave or 3-wire Master Mode. NSS signal is not routed to a port pin. 01: 4-Wire Slave or Multi-Master Mode (Default). NSS pin is configured as an input. 1X: 4-Wire Single-Master Mode. NSS pin is configured as output and outputs SPI_CR1[2] value.
[1]	TXBMT	Transmit Buffer Empty Flag 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. 0: A new byte is written to the transmit buffer. 1: Data in the transmit buffer has been transferred to the shift register.
[0]	SPIEN	SPI Enable 0: Disable 1: Enable

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.

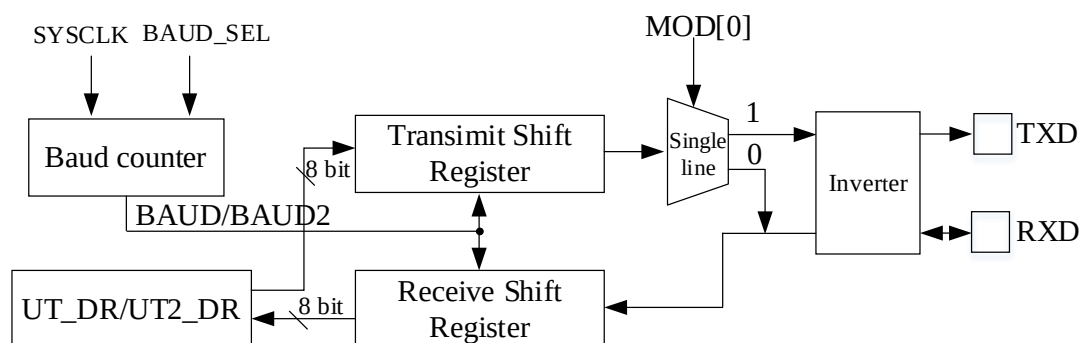


Figure 10-1 UART Block Diagram

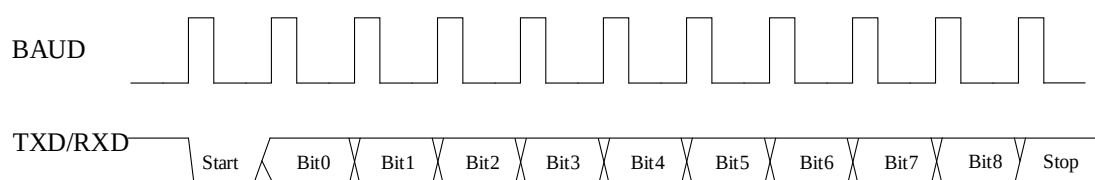


Figure 10-2 UART Timing Diagram

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 9th 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 9th 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 9th 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 9th 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 9th 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 9th 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 9th 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 9th 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 Baud rate = $\text{SYSCLK}/(16/(1 + \text{UT\_BAUD}[\text{BAUD\_SEL}]))/(\text{UT\_BAUD}[\text{BAUD}] + 1)$ Example: If baud rate = 9600 and $\text{UT\_BAUD}[\text{BAUD\_SEL}] = 0$, then $\text{UT\_BAUD}[\text{BAUD}] = (24\text{M}/16/9600/(1 + 0)) - 1 = 155$, 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 θ . 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:

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

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

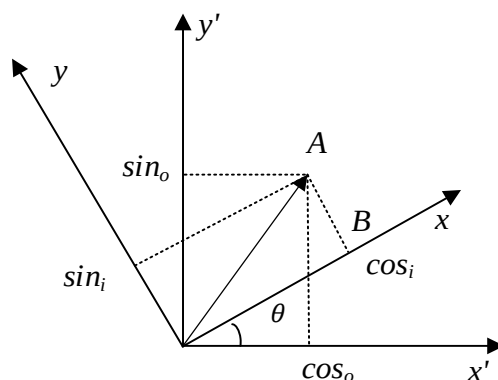


Figure 11-1 Coordinate Transformation

As shown in Table 11-6, $\cos_i$, $\sin_i$, θ , $\cos_o$ and $\sin_o$ are all 16-bit signed data. $\cos_i$ is written to SCATx_COS, $\sin_i$ to SCATx_SIN and θ 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	θ	-
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

θ : Calculated vector angle

U : Calculated vector amplitude

As shown in Table 11-7, $U \cos \theta$ and $U \sin \theta$, U and θ are 16-bit signed data. $U \cos \theta$ is written to SCATx_COS and $U \sin \theta$ to SCATx_SIN to calculate U and θ . U and θ 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	-	θ

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:

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

PID algorithm:

$$U_k = U_{k-1} + K_p \times (E_k - E_{k-1}) + K_i \times E_k + K_d \times (E_k - 2 \times E_{k-1} + E_{k-2})$$

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=0~3) 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 PIx_UK is updated.
4. Read PIx_UK to obtain the output.

Notes:

- The data format of PI_KP is Q12 and that of other registers are Q15.
- PIx_UK and PIx_EK1 values default to the previous calculated U_k and E_k . The related values change after PIx_EK1 and PIx_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  $E_{k-1}$ 
PIx_UKH = Y1;          //Initialize 16 high-order bits of  $U_{k-1}$ 
PIx_UKL = Y2;          //Initialize 16 low-order bits of  $U_{k-1}$ 

```

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[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
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_DA and the 16 low-order bits by DIV1_DA.						

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; θ 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; <i>U</i> 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; θ 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; θ 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 _{k-1} Output: LPF0_Y _k						

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 _{k-1} Output: LPF1_Y _k						

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 _{k-1} Output: LPF2_Y _k						

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 _{k-1} Output: LPF3_Y _k						

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_UKLH(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_UKLH(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

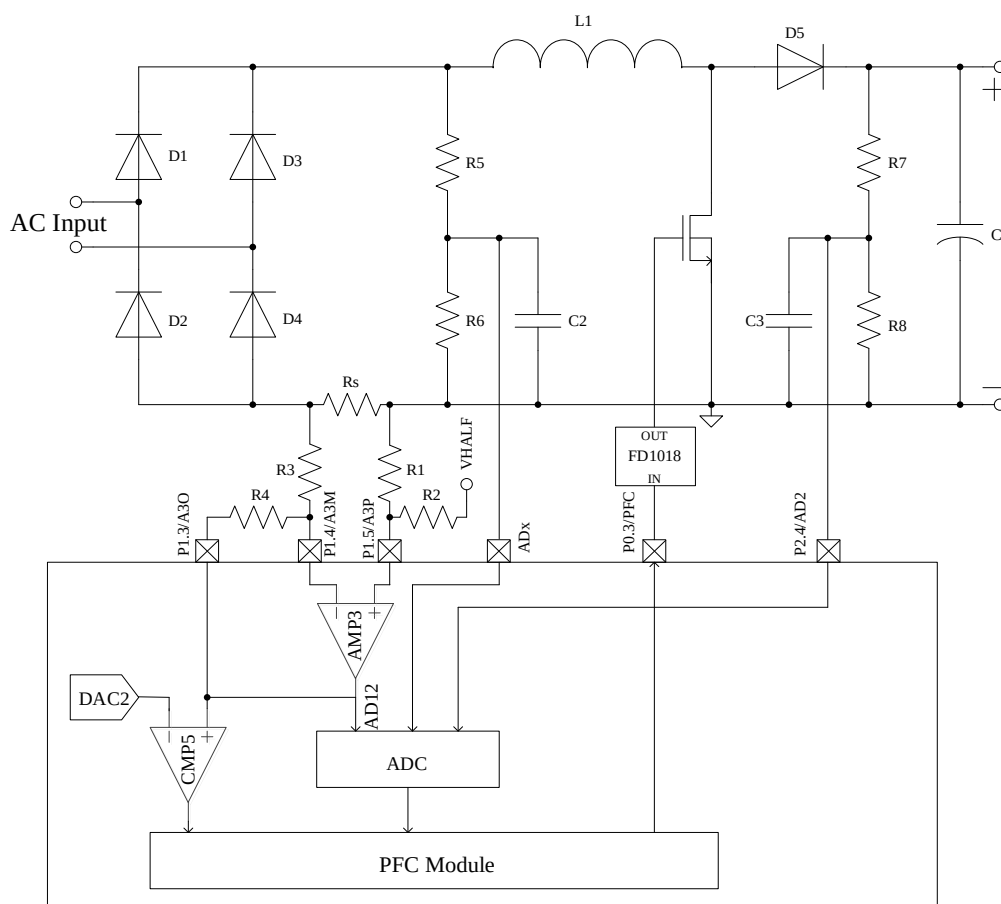


Figure 12-1 Structure Diagram of PFC Module

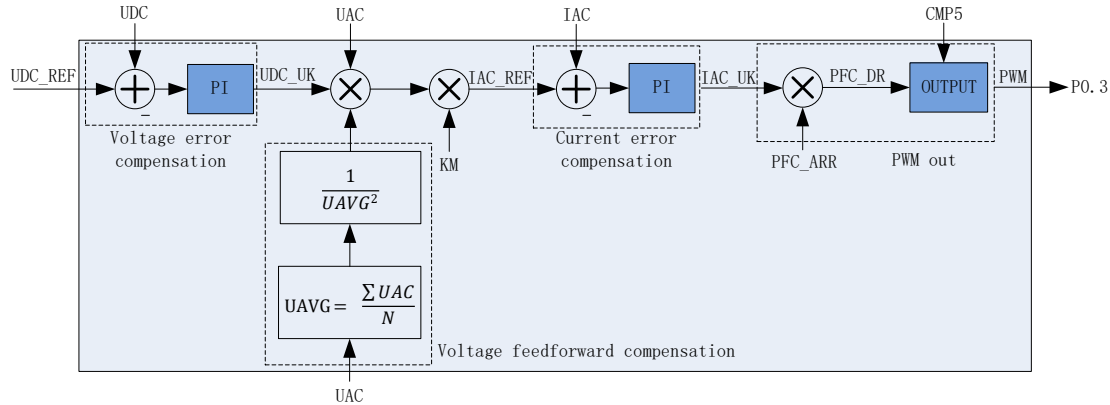


Figure 12-2 Block Diagram of PFC Module

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 UDC_REF (user defined DCV reference) and UDC_UK (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 .

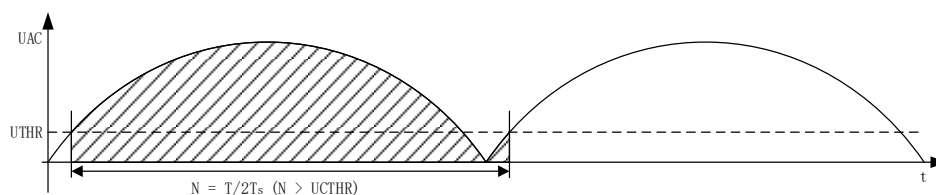


Figure 12-3 Calculation of UAVG

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. Ts 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 IAC_REF (current reference calculated by outer loop) and IAC_UK (sampled current by ADC), which is transmitted to PI controller to generate control output IAC_UK. Inner loop frequency = 24MHz/PFC_ARR.

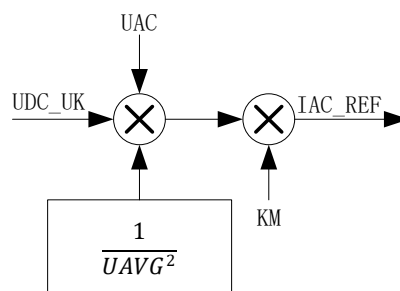


Figure 12-4 Block Diagram of the Calculation of IACREF

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

12.1.6 PWM Output Module

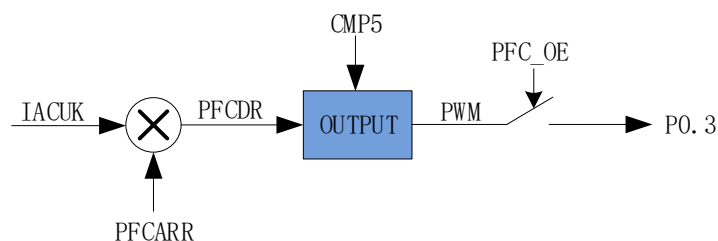


Figure 12-5 Block Diagram of PWM Output

IAC_UK is the duty cycle of PWM module, $\text{duty cycle} = 100\% \times \text{IAC\_UK}/32768$, and PWM signal is generated by comparator and output to P0.3. As shown above, PFC_DR, the value $\text{IAC\_UK} \times \text{PFC\_ARR}/32768$, 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.

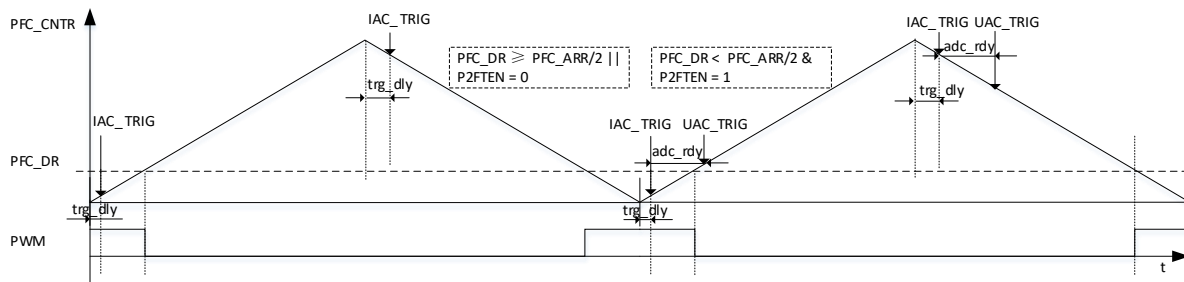


Figure 12-6 Diagram of PWM Output and IAC/UAC Sampling

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 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 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 PFC_CNTR reaches the overflow point. The time delay for sampling is configurable by 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 12
- When $\text{PFC\_CR0}[\text{CCHSEL}] = 0$, a data can be written to 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
Reset	0		0	0	0	-	0	0

Bit	Name	Description
[7:6]	PFC_BLK_MD	When PFC module is disabled ($PFC\_CR0[PFCEEN] = 0$), UDC_PI/IAC_PI works as a general PI controller. $PFC\_CR2[7]$ serves as enable bit of the UDC_PI, and $PFC\_CR2[6]$ as the IAC_PI. 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. 0: Disable. 1: Enable. When PFC module is enabled ($PFC\_CR0[PFCEEN] = 1$), this bit is used to select the mask time for UAC/IAC sampling. 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
[5]	P2FTEN	When PFC module is enabled ($PFC\_CR0[PFCEEN] = 1$), this bit and PFC_DR determine trigger sampling point for IAC sampling. See IAC Sampling for more details.
[4]	DCLREN	PFC Timer Synchronization Enable 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 PFC_DR) if PFC module is disabled. 0: Disable 1: Enable
[3]	PIAUTOEN	UDC_PI/IAC_PI Automatic Enable When PFC module is disabled ($PFC\_CR0[PFCEEN] = 0$), UDC_PI/IAC_PI works as a general PI controller. With this bit enabled, the two PI controllers automatically operate once per cycle of the PFC timer. When $PFC\_CR0[PFCEEN] = 1$, this bit is automatically set to “1”. 0: Disable 1: Enable

[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 CMP5 When input pulse width of CMP5 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 CMP5 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	UACSAMSEL		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]	UACSAMSEL	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 12 when PFC is enabled, otherwise the operational amplifier is unavailable. Table 12-1 ADC Channel Selection for IAC Sampling							
		IAC_TRIG_CH		ADC Channel		IAC_TRIG_CH		ADC Channel	
		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							
		UAC_TRIG_CH		ADC Channel		UAC_TRIG_CH		ADC Channel	
		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_CSO (0x40E2, 0x40E3)

PFC_CSOH(0x40E2)								
Bit	15	14	13	12	11	10	9	8
Name	PFC_CSO[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_CSO[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_CSO	IAC/UAC Sampling Reference Configure PFC_CR0[CCHSEL] to write data to PFC_CSO 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 $PFC\_CSO = 32768 \times 2.5V/5V = 16384$ (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 EK of IAC_PI when PFC is disabled (PFC_CR0[PFCEN] = 0). This register is the IAC reference when PFC is enabled (PFC_CR0[PFCEN] = 1). 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(0x40FE)								
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 = $24000000 / 2 / \text{PFC\_ARR} = 80000\text{Hz}$; the period of outer loop = $80000 / \text{PFC\_OUTARR} = 400\text{Hz}$. 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.

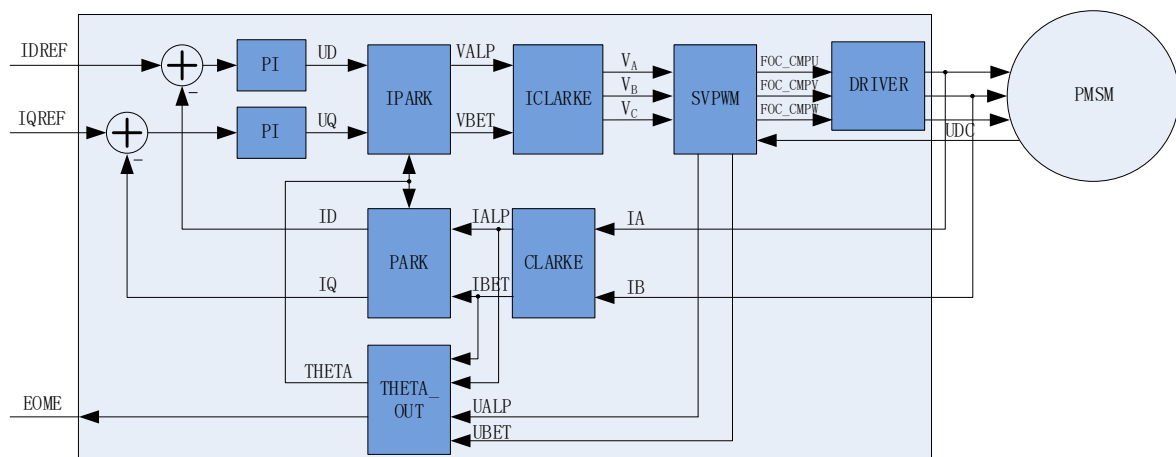


Figure 13-1 FOC Block Diagram

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

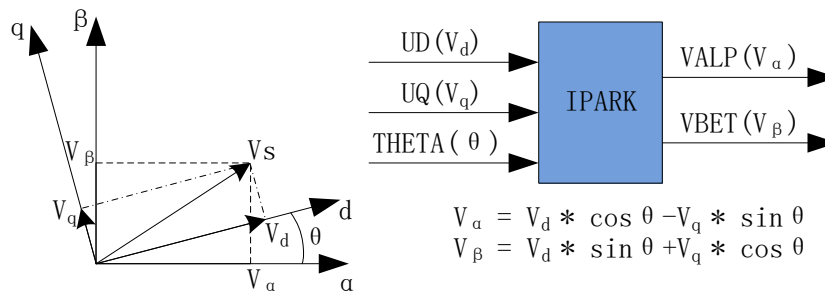


Figure 13-2 Invers Park Transformation

Inverse Park transformation is used to transform two voltage vectors obtained by PI controller, FOC__UD and FOC__UQ, from dq-axis coordinate to αβ-axis coordinate.

13.1.4.2 Inverse Clarke Transformation

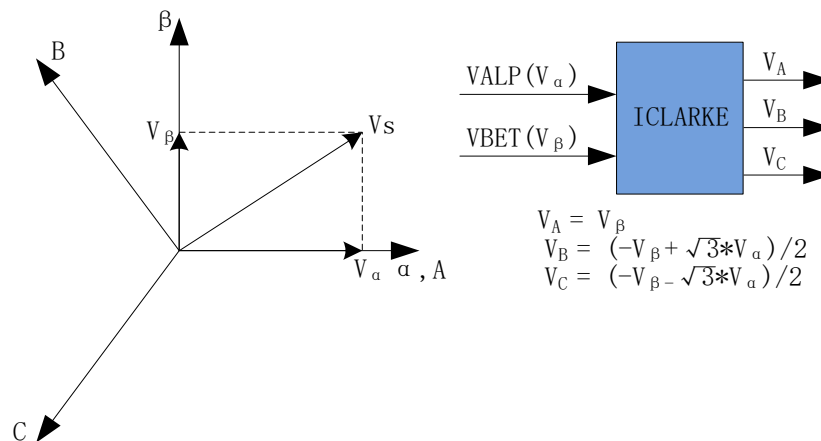


Figure 13-3 Inverse Clarke Transformation

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

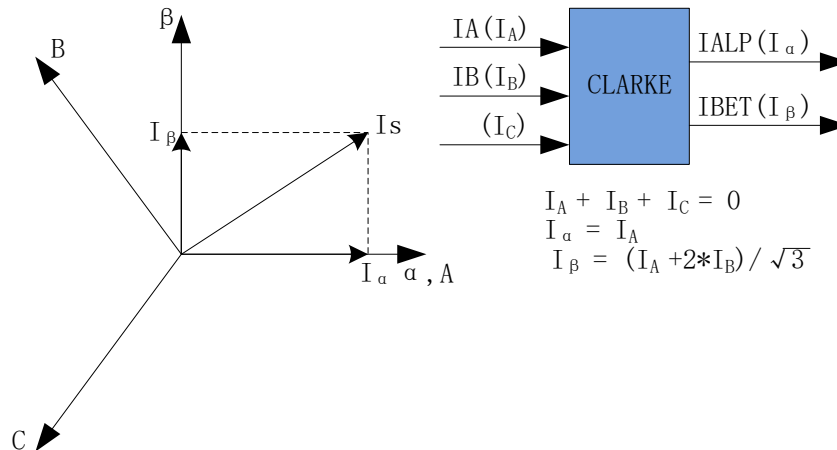


Figure 13-4 Clarke Transform

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

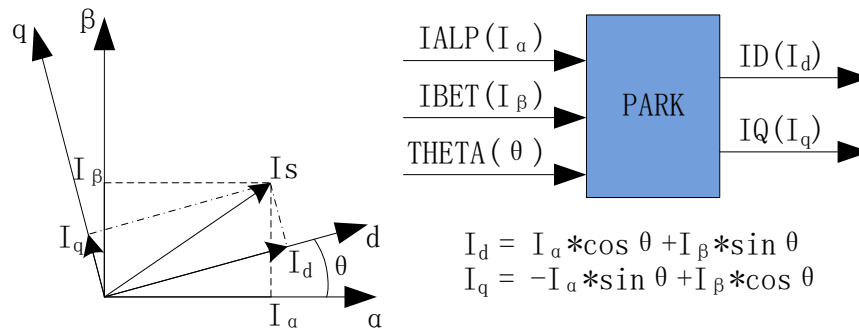


Figure 13-5 Park Transform

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.

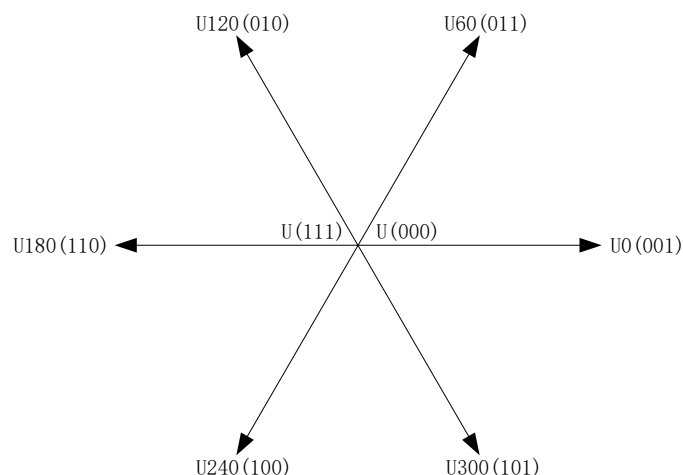


Figure 13-6 SVPWM Voltage Vector

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 $2*T_1$ time and U_{60} applied $2*T_2$ time, is equivalent to the U_{OUT} . The rest of time (T_0) is applied by zero voltage vector.

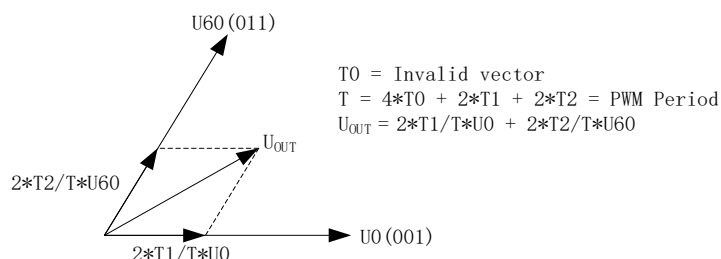


Figure 13-7 SVPWM Voltage Vector Synthesis

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	$2/3*U_{DC}$	0	001
0	1	1	$1/3*U_{DC}$	$1/3*U_{DC}$	011
0	1	0	$-1/3*U_{DC}$	$1/3*U_{DC}$	010
1	1	0	$-2/3*U_{DC}$	0	110
1	0	0	$-1/3*U_{DC}$	$-1/3*U_{DC}$	100
1	0	1	$1/3*U_{DC}$	$-1/3*U_{DC}$	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.

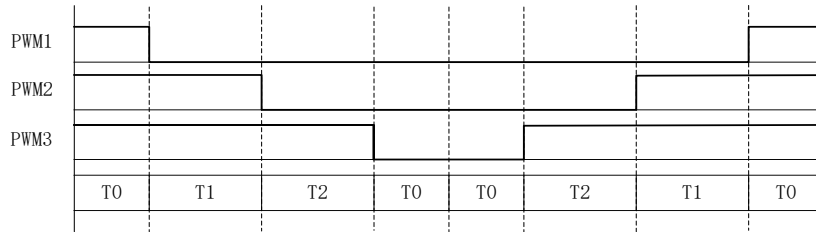


Figure 13-8 Output Level of Continuous SVPWM

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.

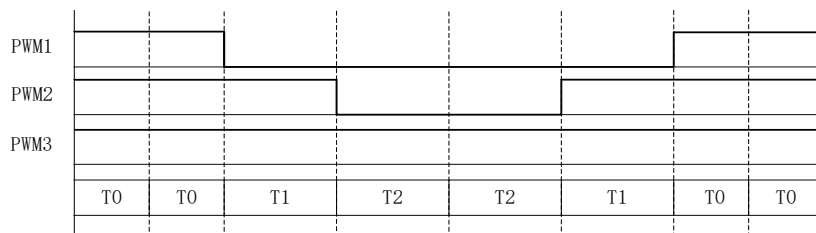


Figure 13-9 Output Level of Discontinuous SVPWM

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 $5 \cdot T = 208\text{ns}$; and if FOC_TRGDLY = 0xFB(-5), the sampling time is advanced by $5 \cdot T = 208\text{ns}$.

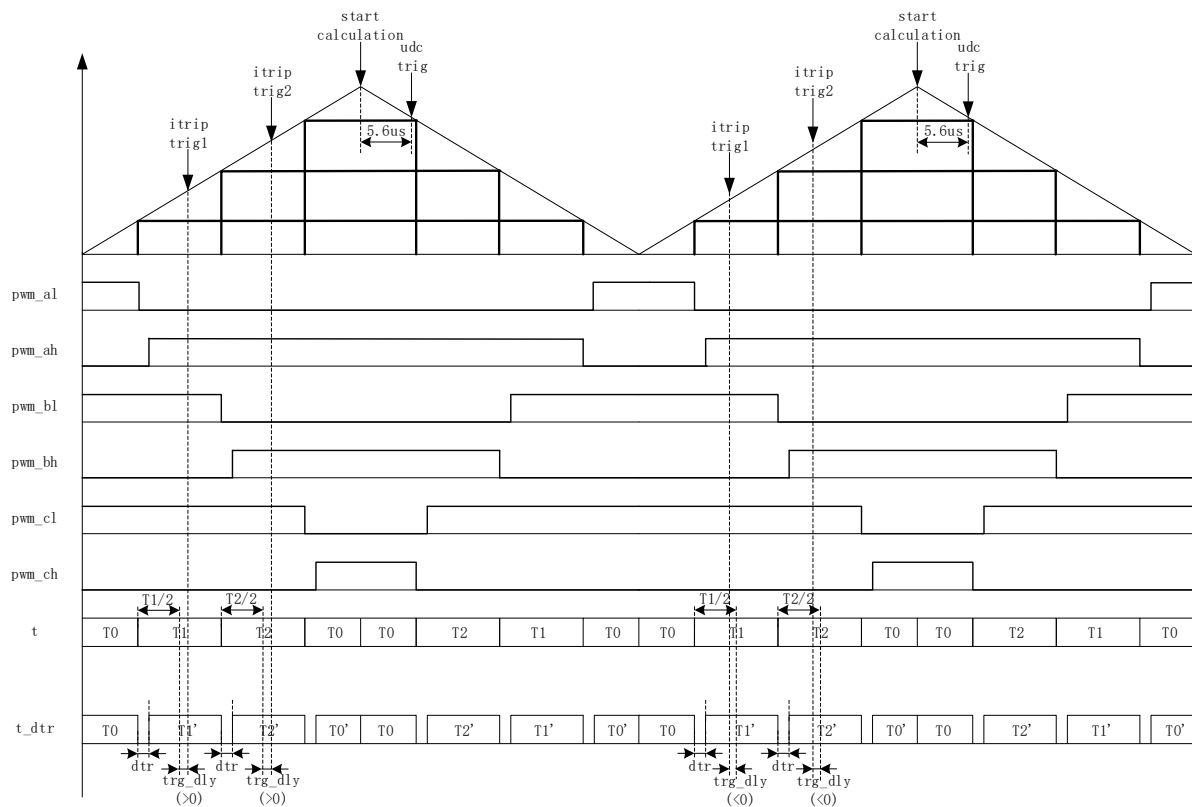


Figure 13-10 Single-shunt Current Sampling Timing

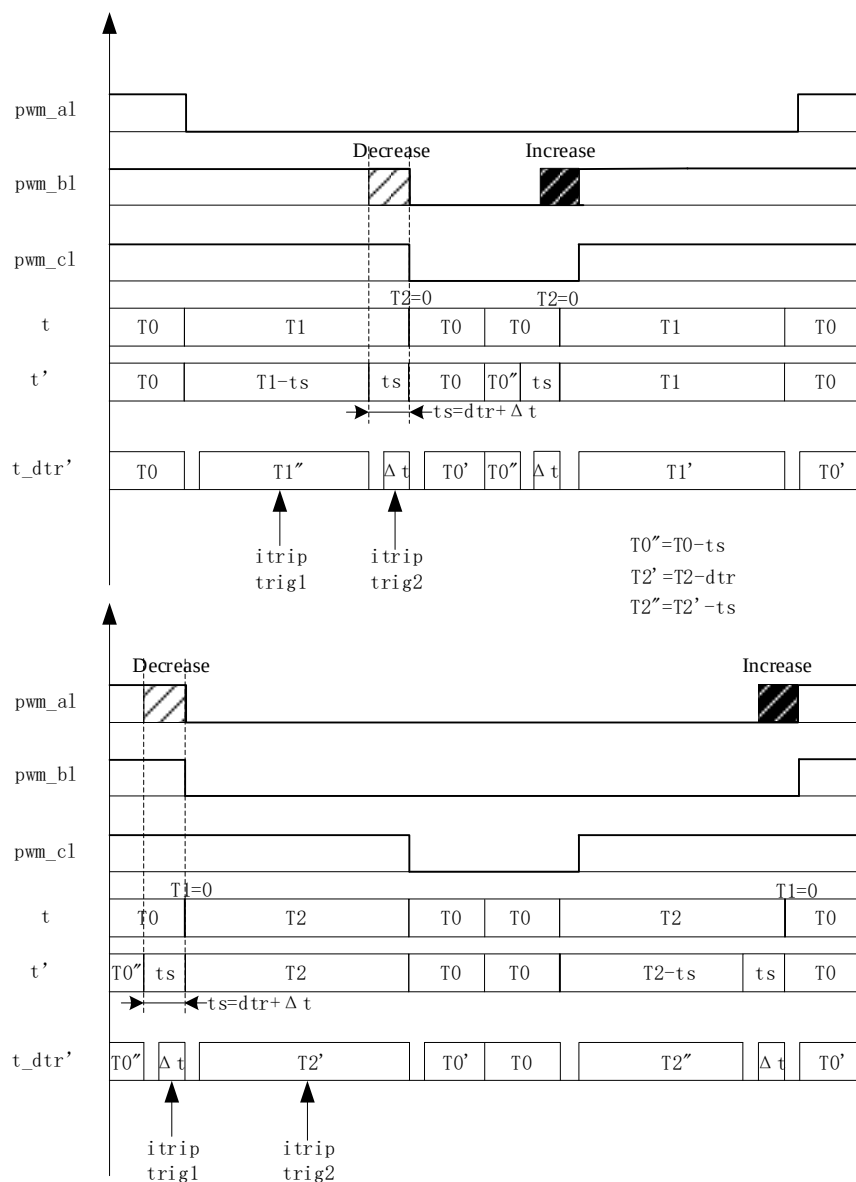


Figure 13-11 Single-shunt Current Sampling Time Compensation

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

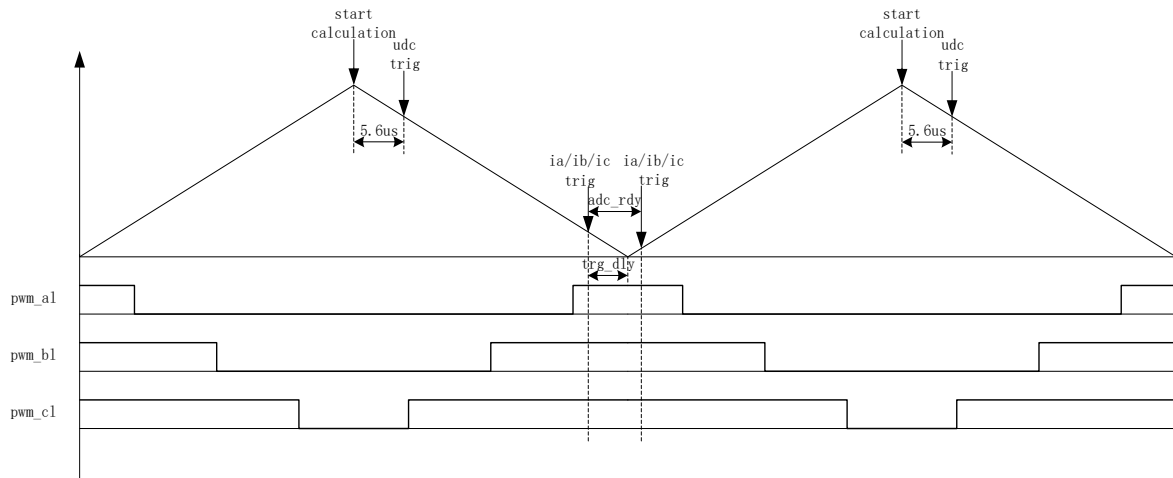


Figure 13-12 Dual/Triple-shunt Sequential Current Sampling Mode

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 $50 \times T = 2.08\mu s$ before an underflow event, and then the other phases of ia/ib/ic are sampled.

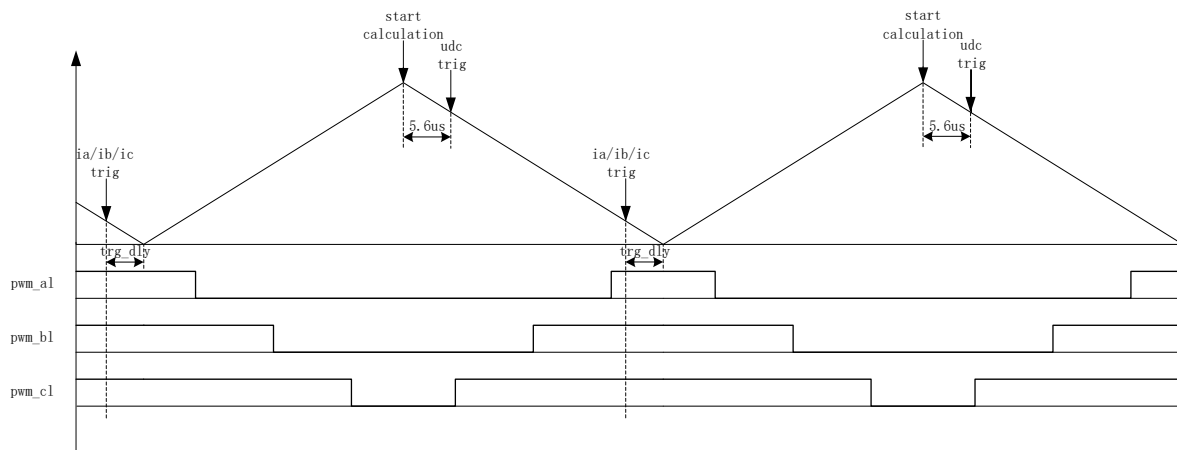


Figure 13-13 Dual/Triple-shunt Alternate Current Sampling Mode

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 $50 \times T = 2.08\mu s$ 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, $FOC\_CSO = 2.5V/5V \times 32768 = 16384$ (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.

13.1.9 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_CR1[RFAE]	FOC_CR1[ANGM]	FOC_CR1[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

13.1.9.1 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).

13.1.9.2 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.)

13.1.9.3 Estimator Output Angle

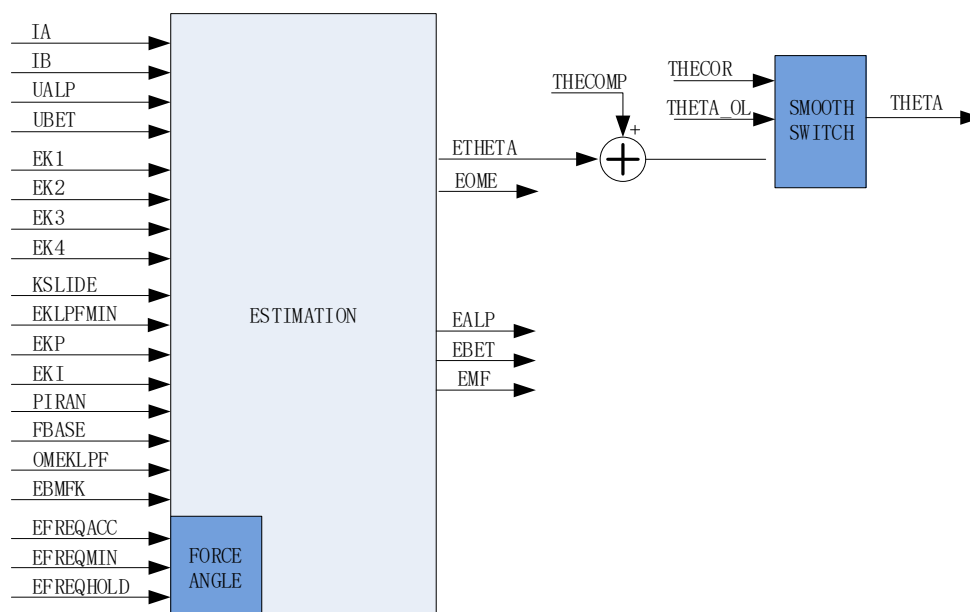


Figure 13-14 Schematic Block Diagram of Estimator

13.1.9.3.1 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.

13.1.9.3.2 Forced Angle of Estimator

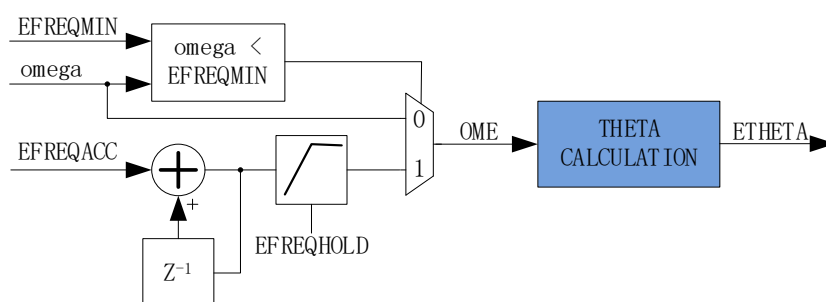


Figure 13-15 Schematic Diagram of Forced Angle of Estimator

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 (ω) and FOC_EFREQMIN to determine ω 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 $\omega \geq \text{FOC\_EFREQMIN}$, ω 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.

13.1.9.3.3 Angle Smooth Switching

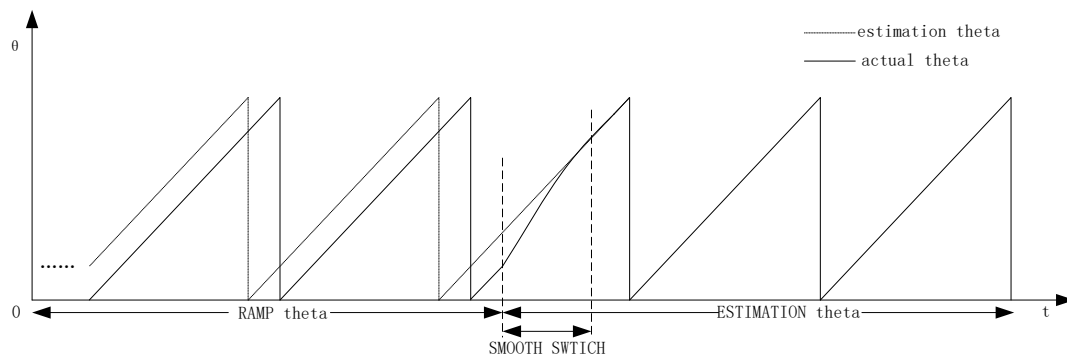


Figure 13-16 Angle Smooth Switching Curve

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.

13.1.9.3.4 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.

13.1.10 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
- α -axis voltage FOC__VALP, β -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
- α -axis current (equal to FOC__IA), β -axis current FOC__IBET
- α -axis BEMF FOC__EALP, β -axis BEMF FOC__EBET
- Magnitude of BEMF FOC__EMF
- Motor power FOC__POW

13.1.10.1 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.

13.1.10.2 BEMF Detection

Estimator estimates α -axis BEMF FOC__EALP and β -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.

13.1.10.3 Motor Power

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

13.1.11 FG Output Generation

FG signal is generated by FOC module and Timer4. FOC module calculates an FG result based on frequency base fbase, 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: $FOC\_KFG = SYSCLK / (2^{TIM4\_CR0[T4PSC]} \cdot f_{base} \cdot x)$, 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_EFREQMAX Flag 0: omega ≤ FOC_EFREQMAX 1: omega > FOC_EFREQMAX						
[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 Selection 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 Selection 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

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] $T_{SMIN} = \text{sampling window } T_{\text{window}} + \text{deadtime } T_{DT}$ Example: Assuming that $T_{\text{window}} = 1\mu\text{s}$, $T_{DT} = 1\mu\text{s}$, $T_{SMIN} = 2\mu\text{s}$ and carrier period = 62.5 μs , then $\text{FOC\_TSMIN} = (1 + 1)/62.5 * 4096 = 131$.

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	Narrow Pulse Elimination for High-side of the Bridge 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. Range [0, 255] Example: Assuming that it is required to remove narrow pulses with less than 1μs width, deadtime $T_{DT} = 1\mu s$, and carrier period = 62.5μs, then $FOC\_TGLI = (1 + 1)/62.5 \times 4096 = 131$.						

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	Sampling Masking Time in Triple-shunt Current Sampling Mode 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. Range [0, 255] Example: Assuming that the phase current is not sampled if the low-side is turned on for less than 1μs, then $FOC\_TBLO = 1000ns/41.67ns = 24$.						

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	Time Configuration for Current Sampling When FOC_TRGDLY is set to "0", FOC module samples the current as follows. Single-shunt Current Sampling Mode: Midpoint between deadtime and applied time of active voltage vector Dual/Triple-shunt Current Sampling Mode: Midpoint of vector 000 (Driver count value = 0). Range [-128, 127] Single-shunt Current Sampling Mode: If FOC_TRGDLY = 5, it delays by $5 \times T = 208ns$ to sample the current, and if FOC_TRGDLY = 0xFB (complement) or FOC_TRGDLY = -5, it advances by $5 \times T = 208ns$. 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 $5 \times T = 208ns$ before an overflow event occurs. If FOC_TRGDLY = 5 and Driver timer counts up, it samples the current at $5 \times T = 208ns$ after an overflow event occurs.						

13.2.9 FOC_CSO (0x40A6, 0x40A7)

FOC_CSOH(0x40A6)								
Bit	15	14	13	12	11	10	9	8
Name	FOC_CSO[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_CSOL(0x40A7)								
Bit	7	6	5	4	3	2	1	0
Name	FOC_CSO[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_CSO	Current Sampling Offset FOC_CR2[CSOC] is configured to select the current, and FOC_CSO 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. Range [0, 32767]. The MSB is always 0 Example: Assuming that the ADC voltage falls within 0V ~ 5V with a reference value of 2.5V, then $FOC\_CSO = 2.5V/5V * 32768 = 16384(0x4000)$						

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	Speed of Ramping Module FOC_RTHERSTEP is an internal 32-bit variable. MSB is sign bit. High-order 16 bits are written by software. Range [-32768.32767] $FOC\_RTHERSTEP(32\text{ bits}) = FOC\_RTHERSTEP(32\text{ bits}) + FOC\_RTHERACC(16\text{ low-order bits})$ $THETA\_OL(16\text{ bits}) = THETA\_OL(16\text{ bits}) + FOC\_RTHERSTEP(16\text{ high-order bits})$						

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)

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)

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		β -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_ID_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	β -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	R	R	R	R	R	R	R	R
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	R	R	R	R	R	R	R	R
Reset	0	0	0	0	0	0	0	0
Bit	Name		Description					
[15:0]	FOC__VALP		α -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 $8192/32768 \times 180^\circ = 45^\circ$.					

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		α -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		β -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] > 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_EKIH(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_EKIL(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_EKLPFMINL(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 DKI(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 $fbase = 200Hz$, $Ts = 62.5\mu s$, 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 rd 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 th 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 st 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 nd 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_UDCFLTL(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.

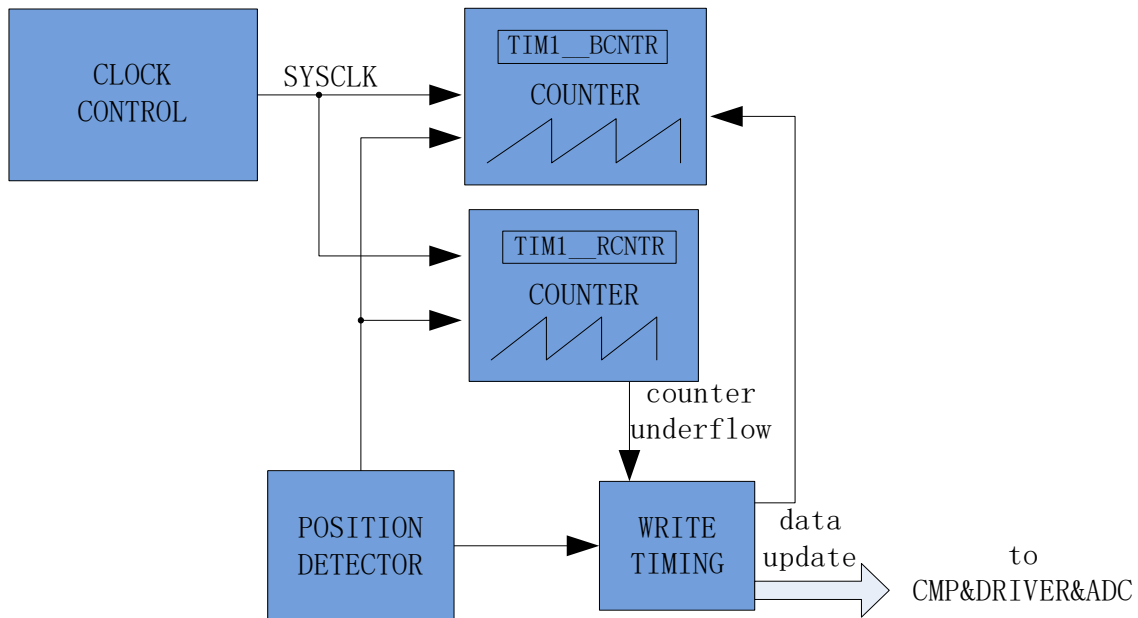


Figure 14-1 Timer1 Internal Structure

14.1.1 Timer1 Counter Module

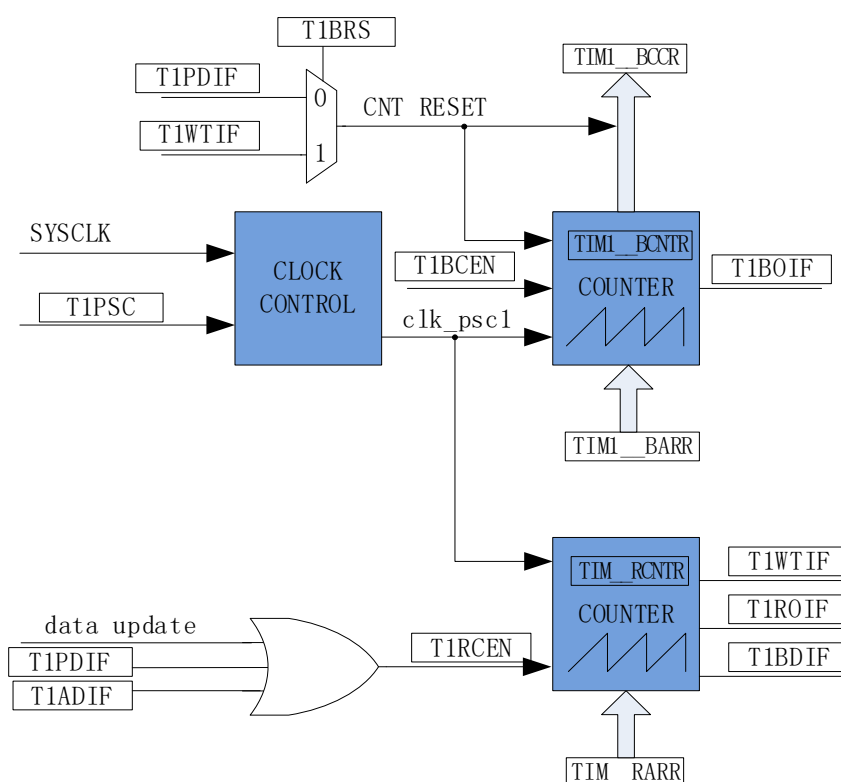


Figure 14-2 Timebase Unit

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_BCNTR register. TIM1_BCNTR 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_BCNTR 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_BCNTR 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.

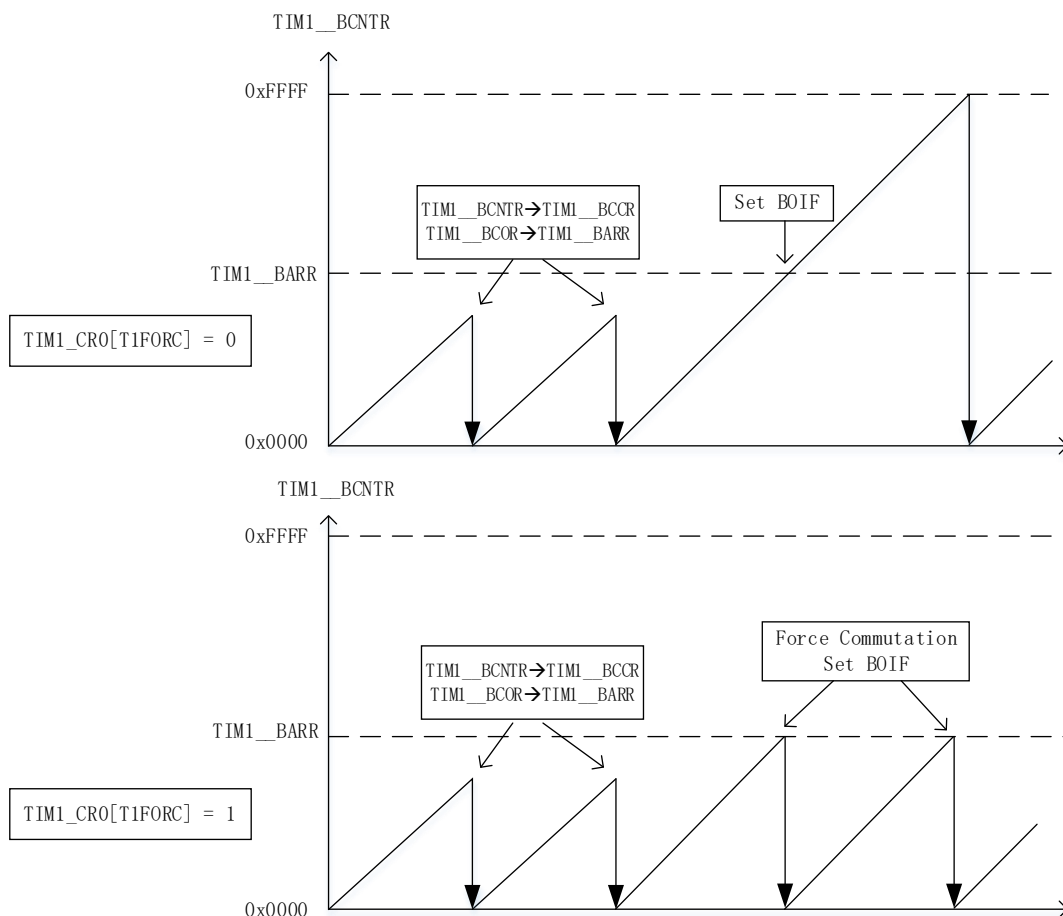


Figure 14-3 Waveform of Base Timer

In Manual mode (TIM1_IER[T1MAME] = 1), TIM1_BCNTR 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.

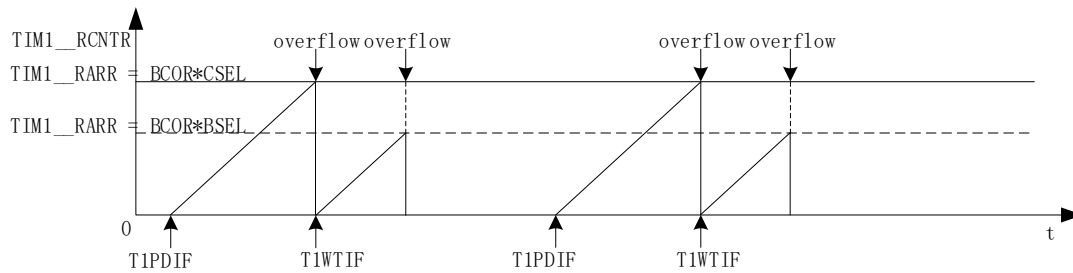


Figure 14-4 Waveform of Reload Timer

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.

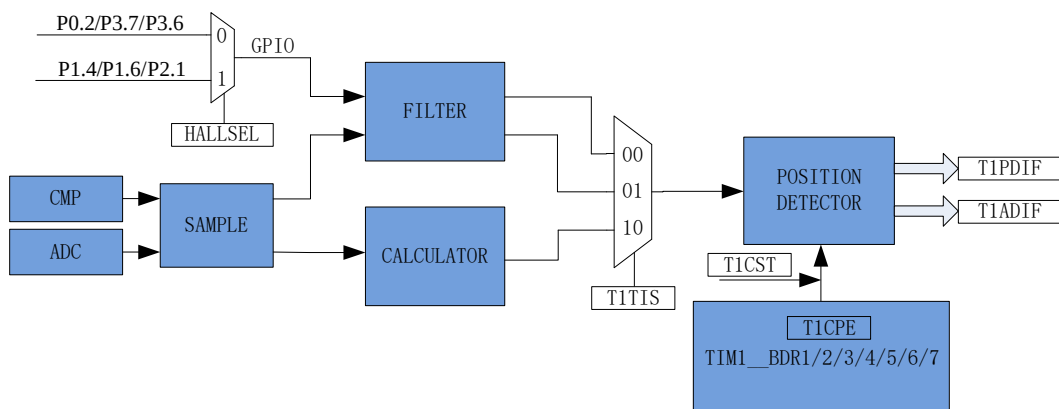


Figure 14-5 Functional Block Diagram of Position Detection

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.

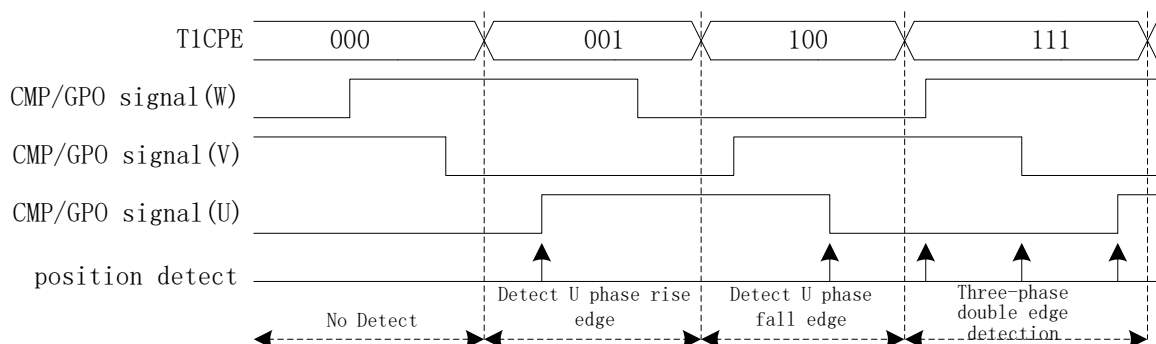


Figure 14-6 Timing Diagram of CMP/GPIO Position Detection

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

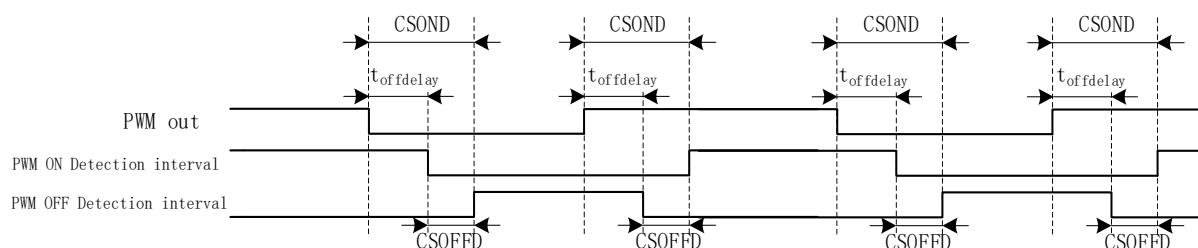


Figure 14-7 Timing Diagram of Sampling

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

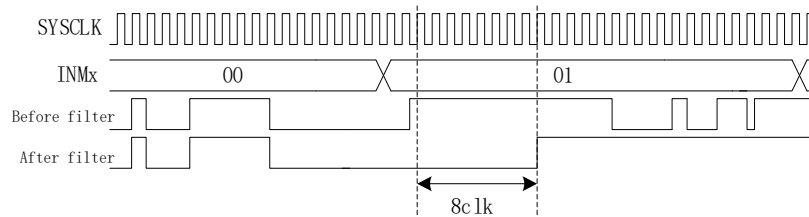


Figure 14-8 Timing Diagram of Filtering Module

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

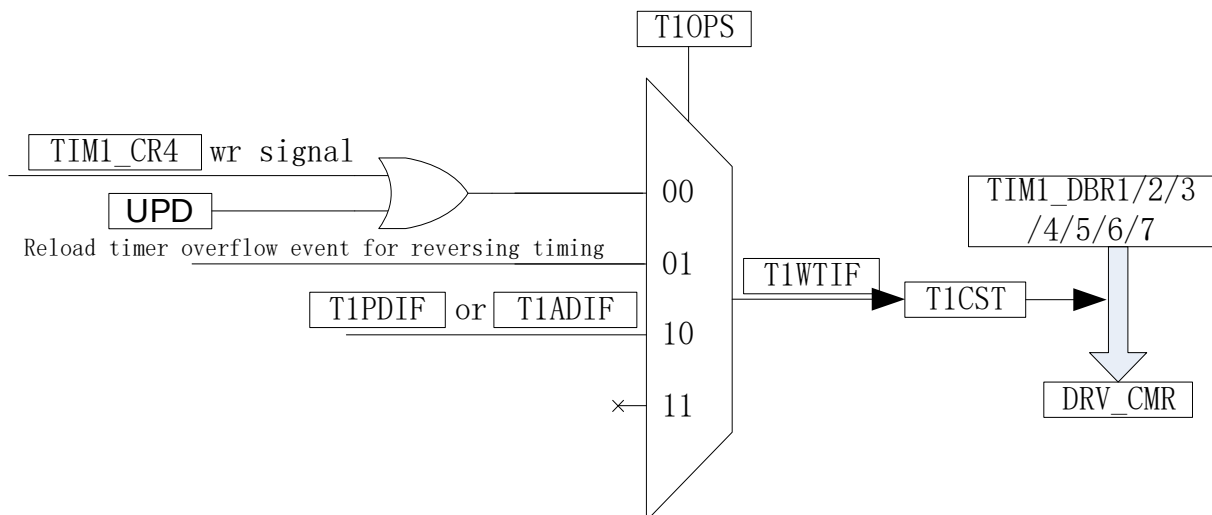


Figure 14-9 Write Timing Block Diagram

When the control logic, predefined in TIM1_DBR1/2/3/4/5/6/7, is sent to driver register DRV_CMRR, a writing sequence interrupt is generated. The triggered source is selected by the configuration of TIM1_CR0[T10PS], 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

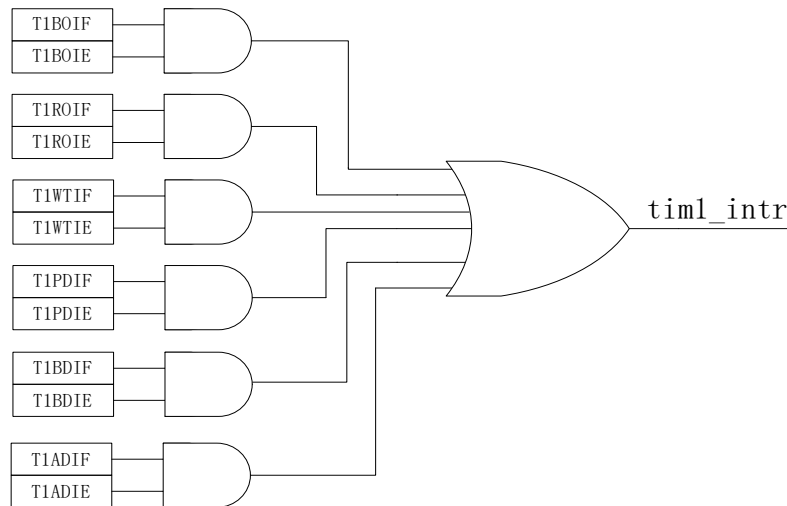


Figure 14-10 Timer1 Interrupt Sources

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

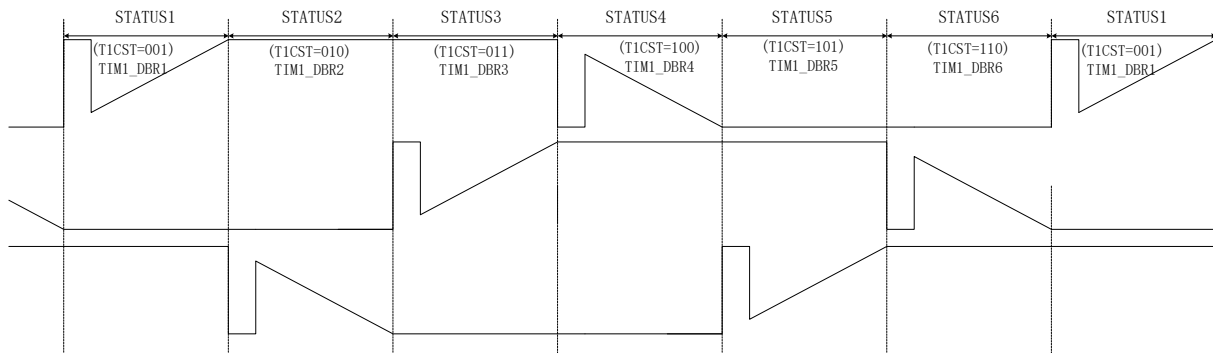


Figure 14-11 Diagram of Six-step Phase Commutation of Square Wave Control

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[CMP0SEL] for phase commutation and position detection.

14.2.2 Square Wave Control Working Principle

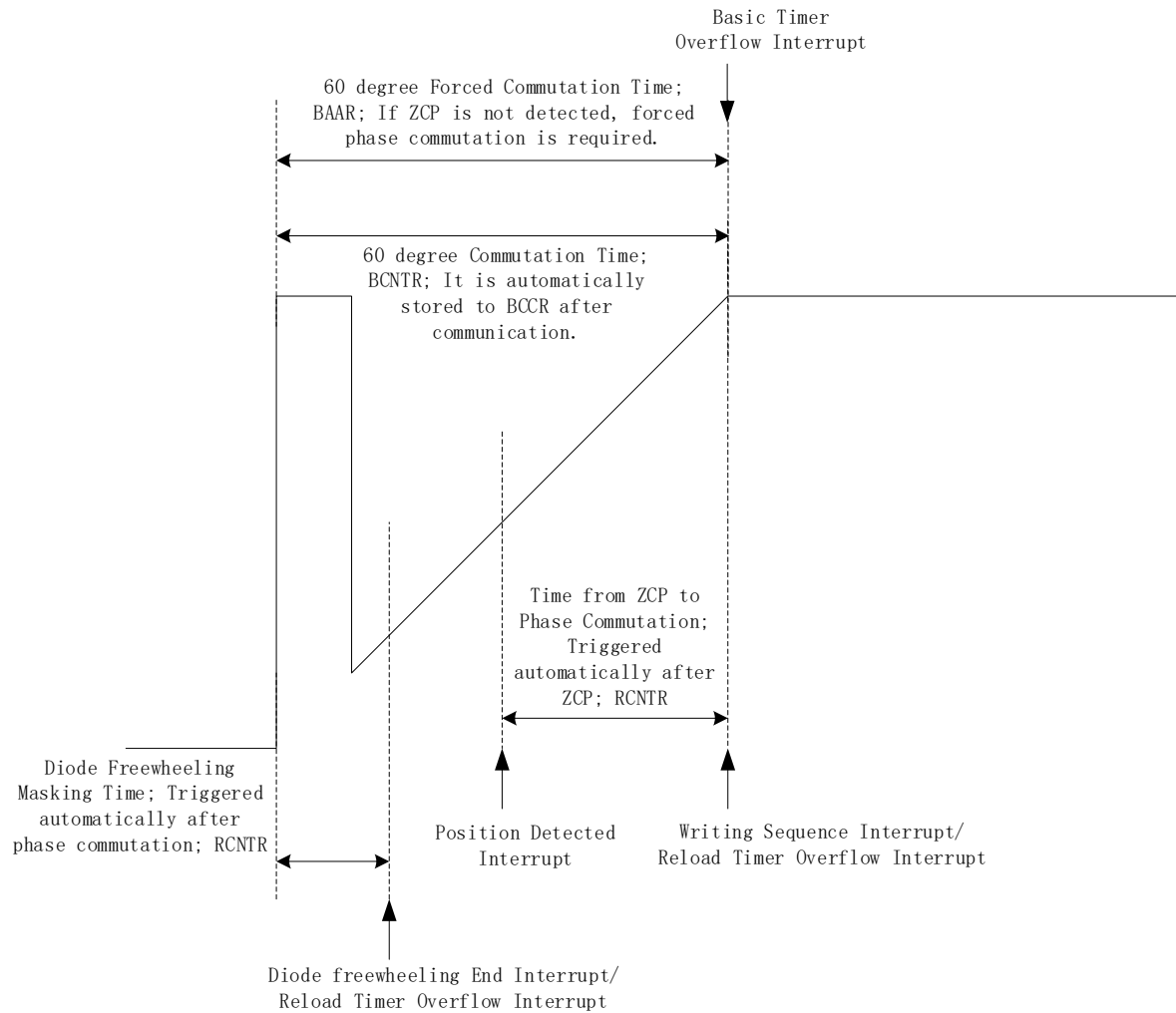


Figure 14-12 Square Wave Control Working Principle

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 an 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 = $TIM1\_CR1[BSEL]/128 \times 60^\circ$.

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 = $TIM1\_CR2[CSEL]/128 \times 60^\circ$.

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_CMV. 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						
		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_BCNT 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_RCNTR 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__BCNTR 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__RCNTR is cleared to “0” when TIM1__RCNTR matches TIM1__RARR. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: No effect

[2]	T1WTIF	Writing Sequence Interrupt Flag Writing Sequence Interrupt is generated when TIM1_DBRx is transferred to DRV_CMCR. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: No effect.
[1]	T1PDIF	CMP/GPIO Position Detected Interrupt Flag A position detected interrupt is generated when CMP/GPIO Position Detection matches TIM1_DBRx[T1CPE]. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: No effect
[0]	T1BDIF	Diode Freewheeling Masking End Interrupt Flag Diode freewheeling masking starts after phase commutation and an interrupt is generated at end. Read: 0: No Interrupt Pending 1: Interrupt Pending Write: 0: This bit is cleared to “0”. 1: No effect

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
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	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

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.						

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	15	14	13	12	11	10	9	8
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	15	14	13	12	11	10	9	8
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_URES[15:8] (0x4090)								
Bit	15	14	13	12	11	10	9	8
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] (0x4091)								
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_KF[15:8] (0x4094)								
Bit	15	14	13	12	11	10	9	8
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_KF[7:0] (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

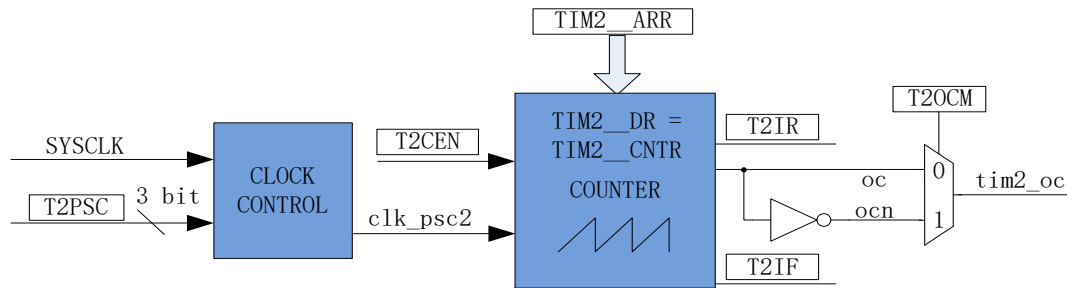


Figure 15-1 Output Mode Block Diagram

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 = $\text{TIM2\_DR} / \text{TIM2\_ARR} * 100\%$. If TIM2_CR0[T2OCM] = 0, the low level is output when TIM2_CNTR < TIM2__DR, and the high level is output when TIM2_CNTR ≥ 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

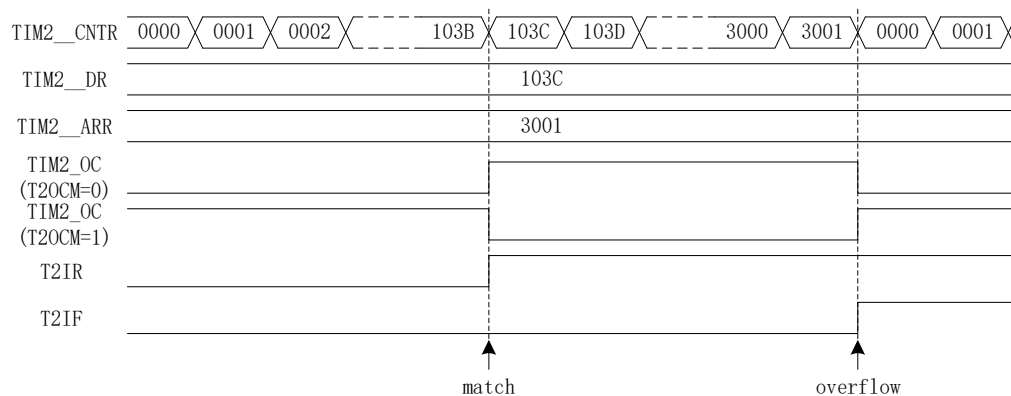


Figure 15-2 Output Mode Waveform

15.1.4 Input Signal Filtering and Edge Detection

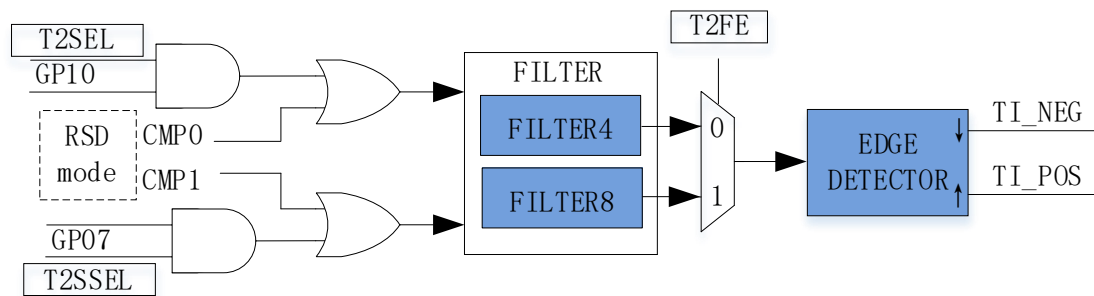


Figure 15-3 Block Diagram of Input Signal Filtering and Edge Detection

The input signal of Timer2 comes from P0.7 or P1.0, set by $PH\_SEL[T2SEL]$ and $PH\_SEL[T2SSEL]$ (see section 22.3.16). 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.

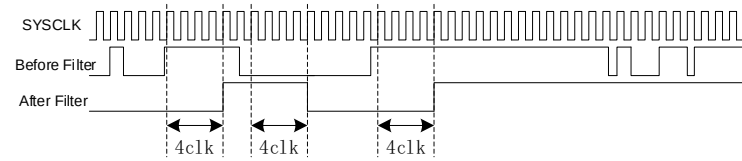


Figure 15-4 Timing Diagram of Filter Module

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

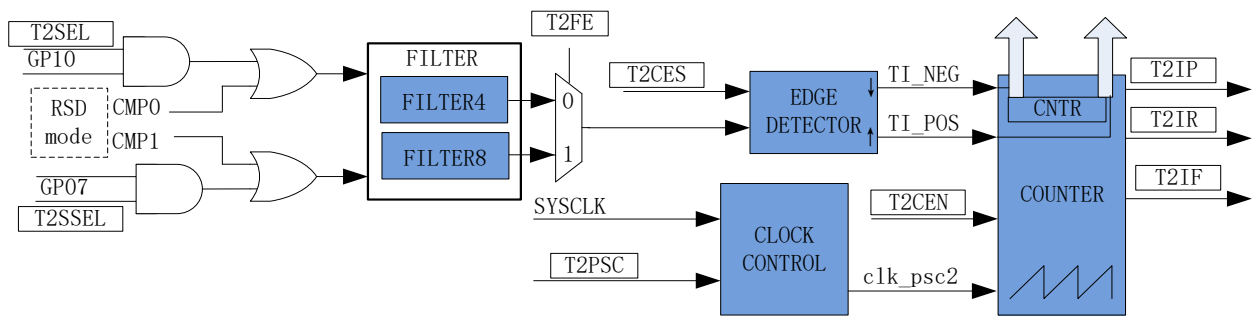


Figure 15-5 Schematic Diagram of Input Capture Mode

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.

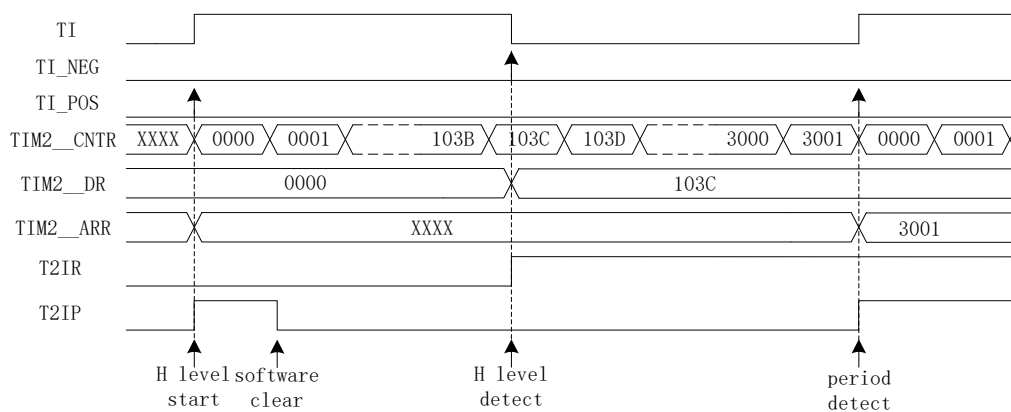


Figure 15-6 Timing Diagram of Input Capture Mode ($TIM2\_CR0[T2CES] = 0$)

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

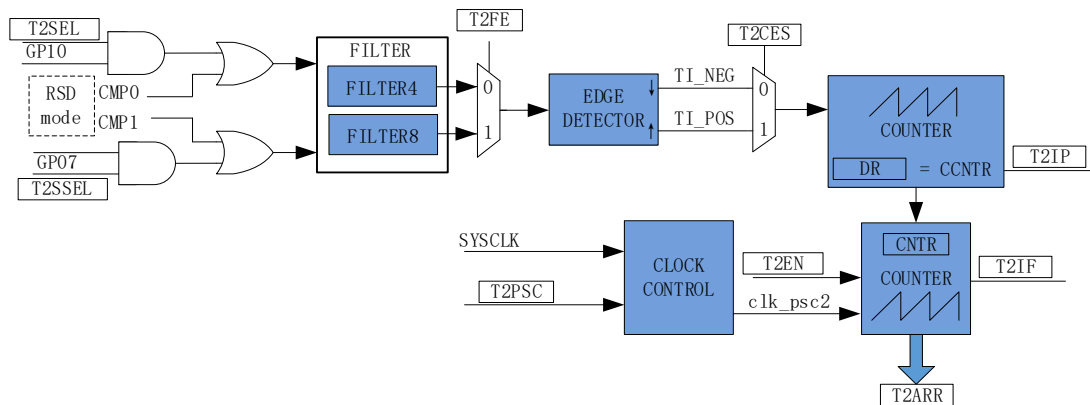


Figure 15-7 Schematic Diagram of Input Counter Mode

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.



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.

The diagram illustrates the internal architecture of the TIM2 peripheral, showing its operation in RSD (Rapid Sampling and Detection) and QEP (Quadrature Encoder Pulse) modes.

Inputs and Modes:

- RSD mode:**
 - CMPO_EN = 1
 - CMPO_MOD = 11
 - CMPO_SEL = 00
- QEP mode:**
 - T2SSEL = 1
 - T2SEL = 1

Internal Blocks and Connections:

- FILTER:** Receives inputs from CMPO0, CMPO1, GP04, GP07, and GP10. It is controlled by T2FE. Its output goes to the Quadrature Decoder.
- Quadrature Decoder:** Receives the filtered signal and outputs T2DIR and an Edge signal.
- CLOCK CONTROL:** Receives SYSCLK and T2PSC. It outputs clr and clk_psc2.
- COUNTER (Top):** Receives T2DIR and the Edge signal. It outputs TIM2_DR and is controlled by TIM2_CNTR.
- COUNTER (Bottom):** Receives clr and clk_psc2. It outputs T2IP and T2IF, and is controlled by TIM2_ARR.

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]).

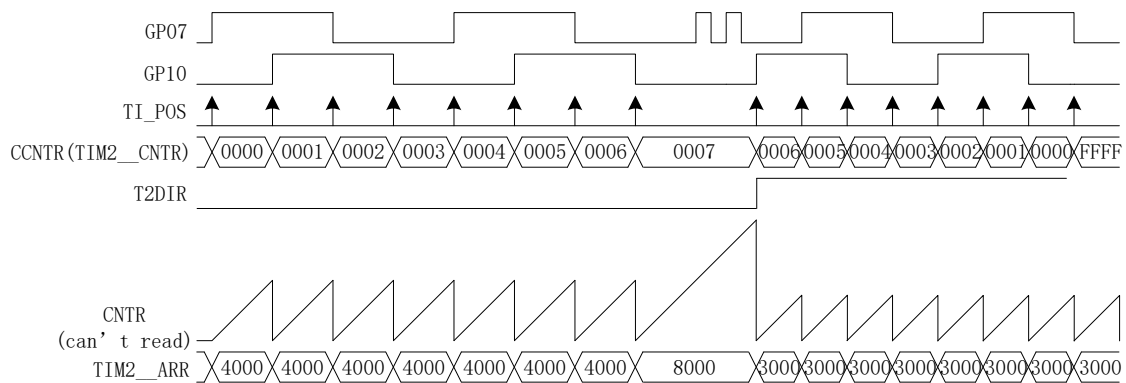


Figure 15-10 Timing Diagram of QEP&RSD Mode

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

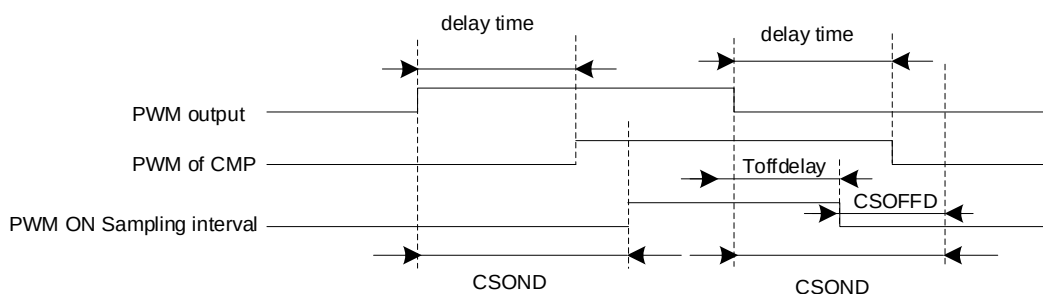


Figure 15-11 PWM ON Sampling Mode

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

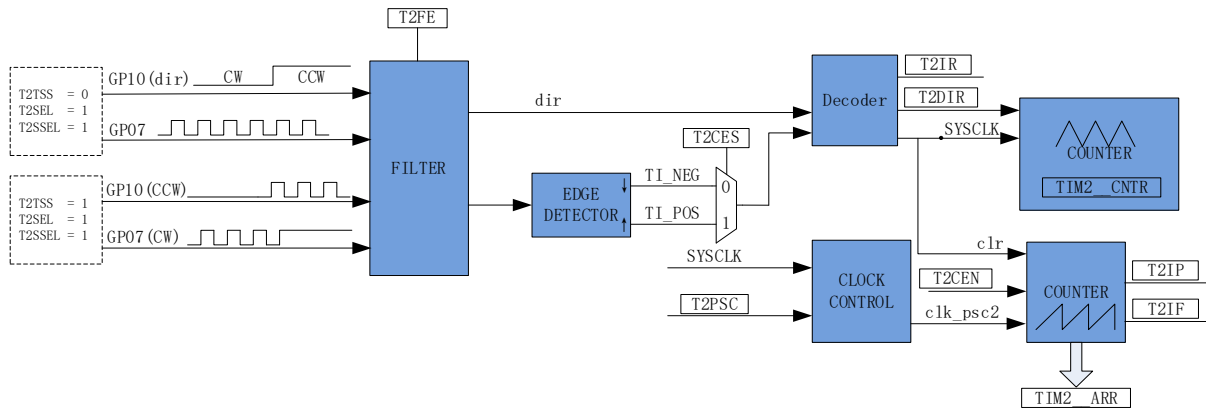


Figure 15-12 Step Mode Schematic Diagram

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.

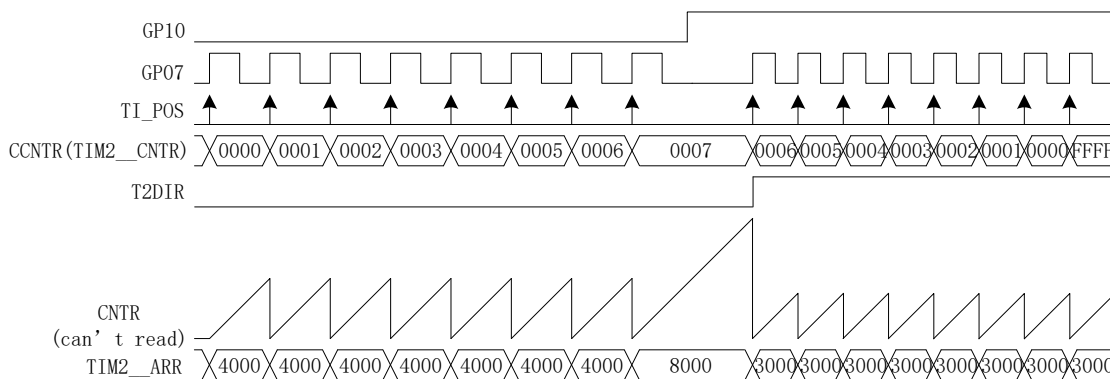


Figure 15-13 Timing Diagram of Step Mode

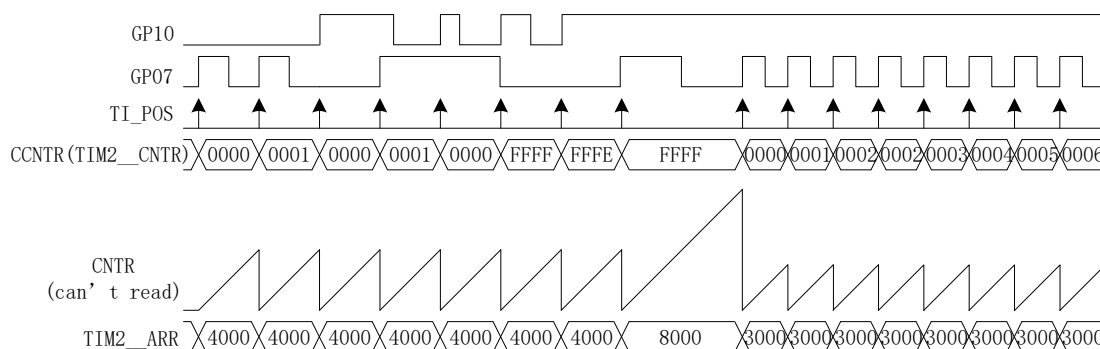


Figure 15-14 Timing Diagram of Positive + Negative Pulse Input State in Step Mode

(Raising Edge Selected as Active Edge)

The special timer is an up/down-counter, and the signal source is active edge of the encoding module. When P1.0 = 0, TIM2_CR1[T2DIR] = 0, the direction is forward. If active edge of P0.7 arrives, the special timer CCNTR increases by 1. When P1.0 = 1, TIM2_CR1[T2DIR] = 1 and the direction is reverse. If active edge of P0.7 arrives, CCNTR decreases by 1. If count value of the special timer reaches 65535 from 0, it is automatically cleared to “0”. If it decreases from 65535 to 0, it is automatically set to 65535. TIM2_CNTR is read to obtain the value of special timer.

The Base Timer is an up counter, which uses the output of prescaler as the clock source to record the time between two active counting edges. When active counting edge arrives, the value of Basic Timer is stored in TIM2_ARR and then 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..

15.2 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 Selection 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 Selection 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 or Step Mode Selection 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 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). 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 Selection 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 Selection 0: Falling Edge Count 1: Raising Edge Count						
[1:0]	T2MOD	Mode Selection 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 Selection 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: $\text{clk\_psc} = \text{SYSCLK} / (2^{\text{TxPSC}})$. 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_psc(Hz)	TIMx_CR0[TxPSC]	Division Factor	clk_psc(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

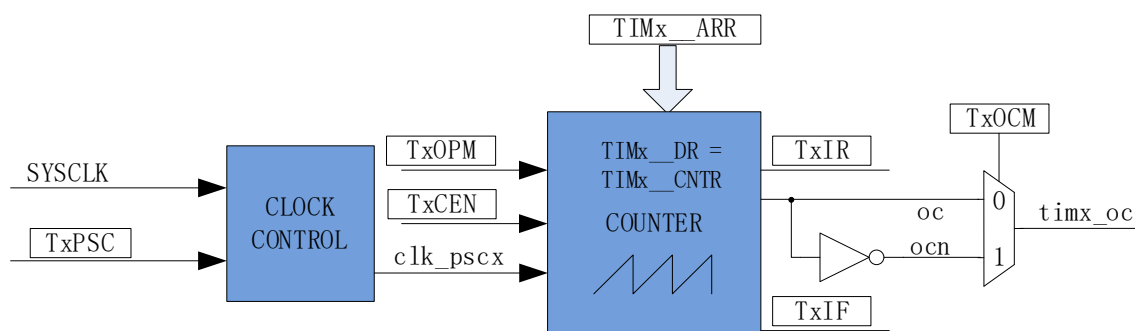


Figure 16-1 Output Mode Block Diagram

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 = $\text{TIMx\_DR} / \text{TIMx\_ARR} * 100\%$. If TIMx_CR0[TxOCM] = 0, the low level is output when TIMx_CNTR < TIMx_DR, and the high level is output when TIMx_CNTR ≥ 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 ≥ 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.

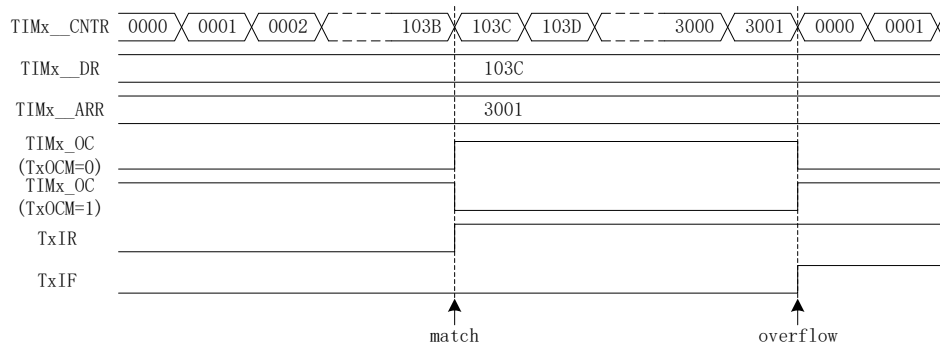


Figure 16-2 Output Waveform of Output Mode

16.1.4 Input Signal Filtering and Edge Detection

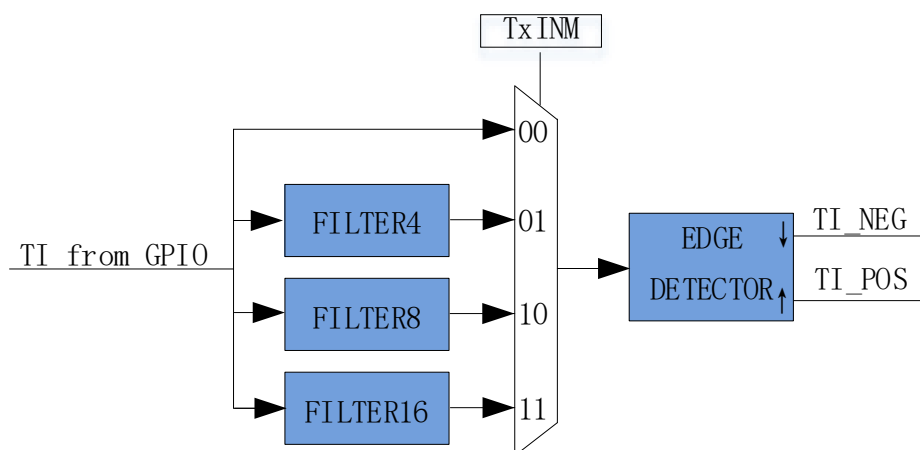


Figure 16-3 Block Diagram of Input Signal Filtering and Edge Detection

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.

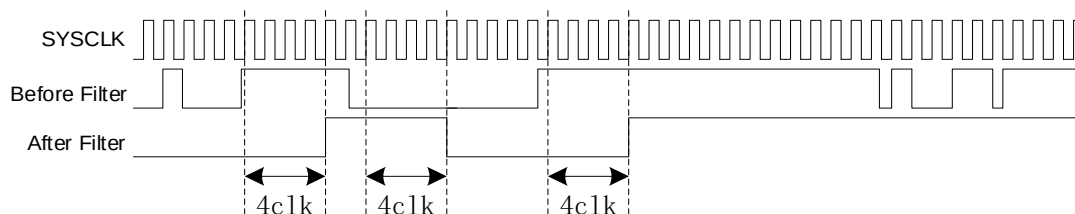


Figure 16-4 Timing Diagram of Filter Module

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

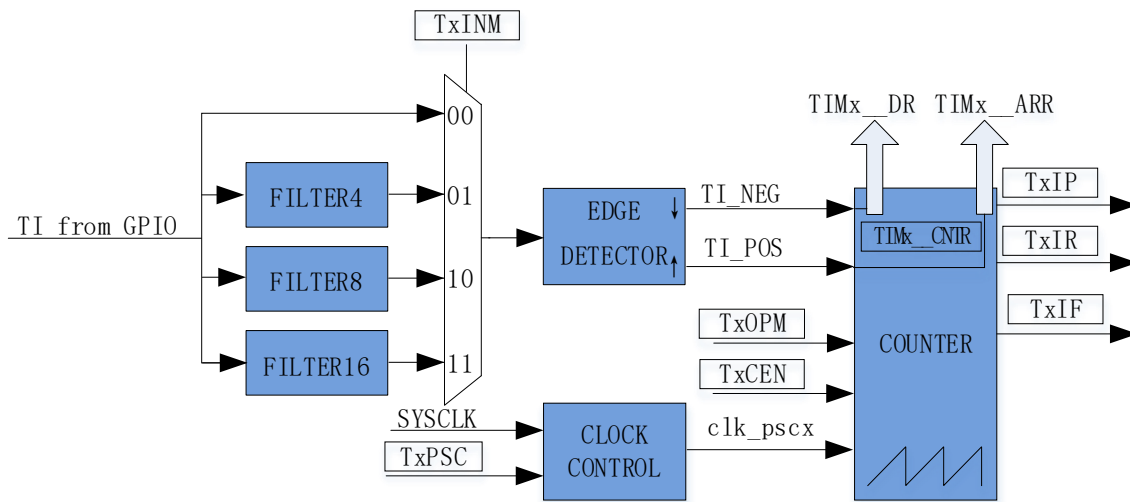


Figure 16-5 Schematic Diagram of Input Capture Mode

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.

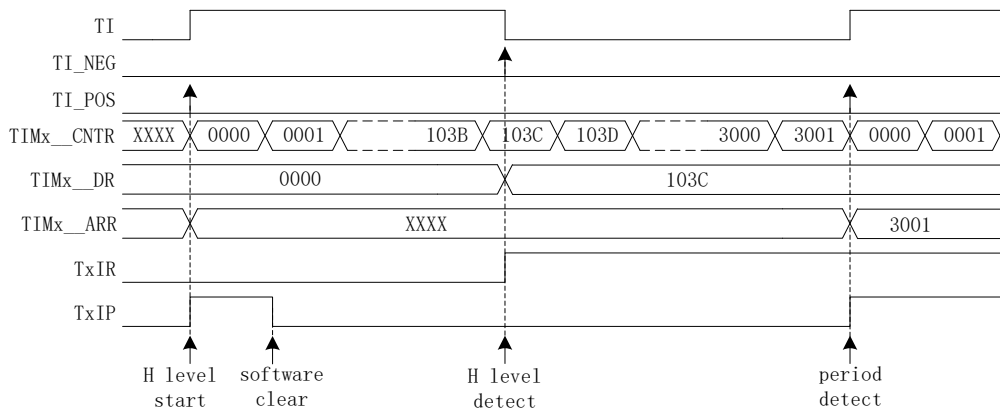


Figure 16-6 Timing Diagram of Input Capture Mode ($TIMx\_CR0[TxOCM] = 0$)

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 Selection 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 Selection 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 Selection 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]						

18.1.1 Driver Introduction

18.1.2 Output Control Module

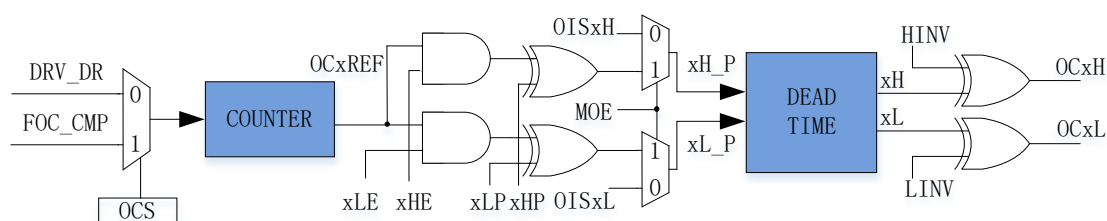


Figure 18-3 Block Diagram of Output Control Module

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 = $\text{DRV\_DR} / \text{DRV\_ARR} * 100\%$.

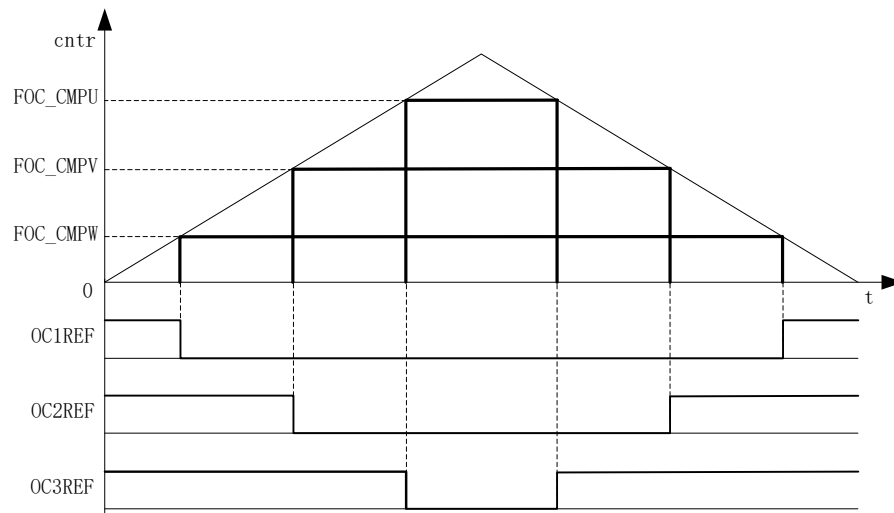


Figure 18-4 PMW Generation

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.

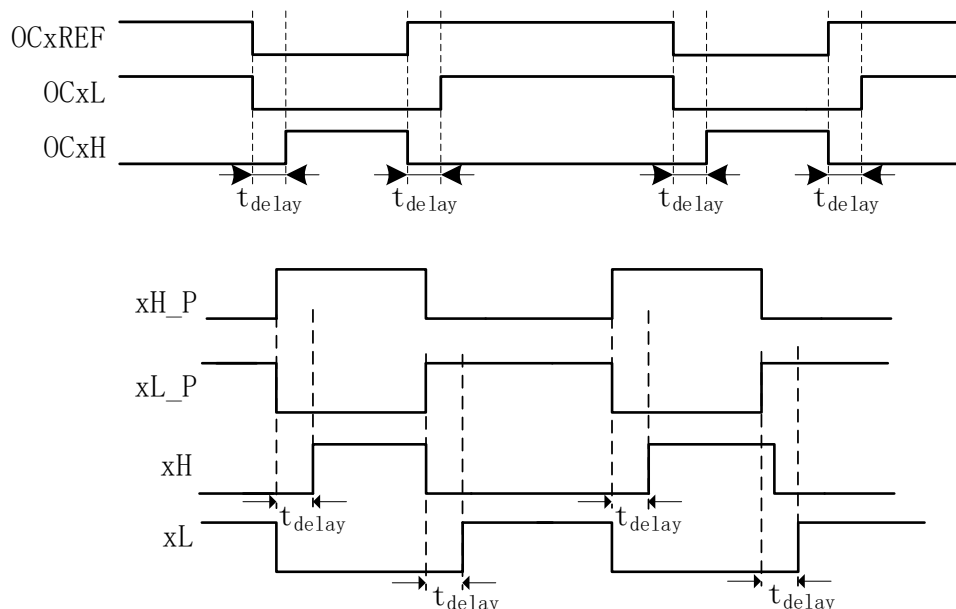


Figure 18-5 Complementary Outputs with Deadtime Insertion

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[R[xHP] and [xLP] to select the polarity of output. For square-wave control, Timer1 automatically controls DRV_CM[R 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[R register.

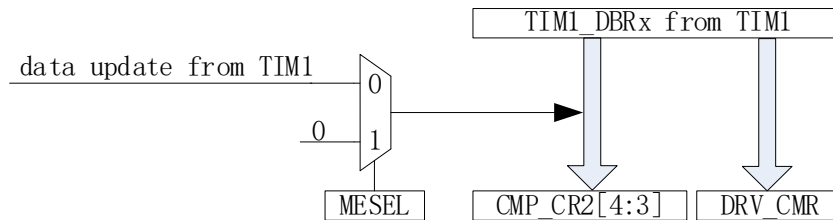


Figure 18-6 Timer1 Automatic Control of DRV_CM[R and CMP_CR2[4:3]

DRV_DR, DRV_ARR and DRV_CM[R 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.

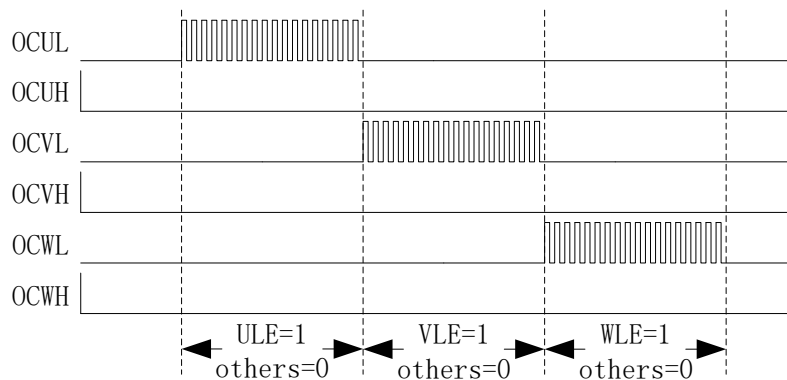


Figure 18-7 Pre-charge Waveform

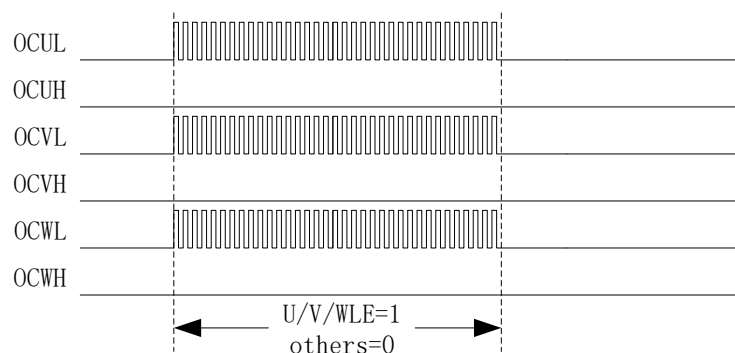


Figure 18-8 Brake Waveform

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.

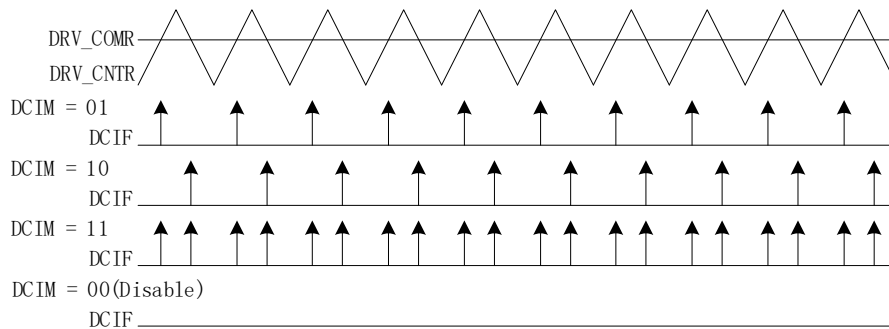


Figure 18-9 Driver Compare Match Interrupt

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/FU6815T)

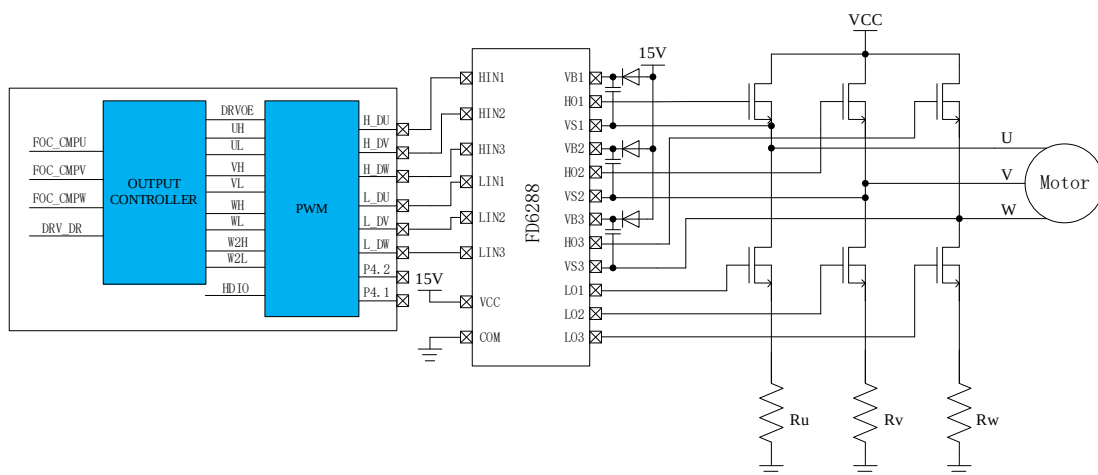


Figure 18-10 Block Diagram of PWM Mode

FU6815L/FU6815T 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.

18.1.4 6N Pre-driver Mode (FU6865Q/FU6864Q/FU6864L)

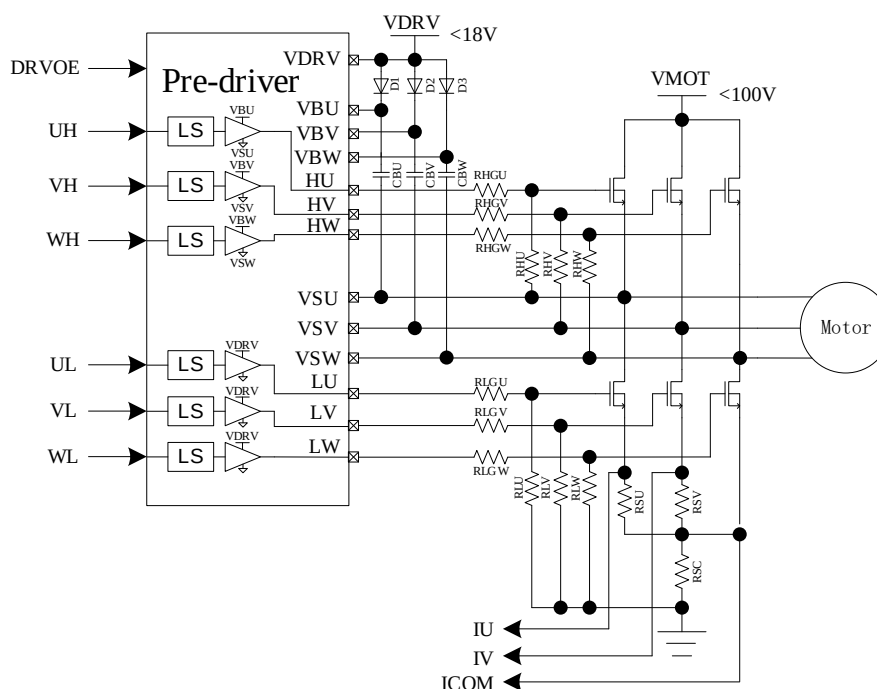


Figure 18-11 Block Diagram of 6N Pre-driver Mode

The features of 6N pre-driver are shown in Figure 18-11. Configuring DRV_CR[DRVOE] enables pre-driver mode, where the pre-driver output is wired to 6 NMOS respectively to drive U/V/W-phases.

Table 18-1 Output Truth Values of FU6865Q/FU6864Q/FU6864L Built-in Pre-driver

Input		Output	
UH/VH/WH	UL/VL/WL	HU/HV/HW	LU/LV/LW
L	L	L	L
L	H	L	H
H	L	H	L
H	H	L	L

18.2 Driver Registers

18.2.1 PI CR (0xF9)

Bit	7	6	5	4	3	2	1	0
Name	T2TSS	RSV				DRVMD	HINV	LINV
Type	R/W	-	-	-	-	R/W	R/W	R/W
Reset	0	-	-	-	-	0	0	0
Bit	Name	Description						
[7]	T2TSS	Input Mode Selection of TIM2 Step Motor 0: Direction +Pulse Input Mode. P1.0 for direction input, and P0.7 for pulse input 1: Bidirectional Pulse Input Mode. P1.0 for backward pulse input, and P0.7 for forward pulse input						
[6:3]	RSV	Reserved						

[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	XLP	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] 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 $\text{Deadtime} = (\text{DRV\_DTR} + 1) * T$ Example: If DRV_DTR is configured to "11", the deadtime = $12 * 41.67\text{ns} = 500\text{ns}$. 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)

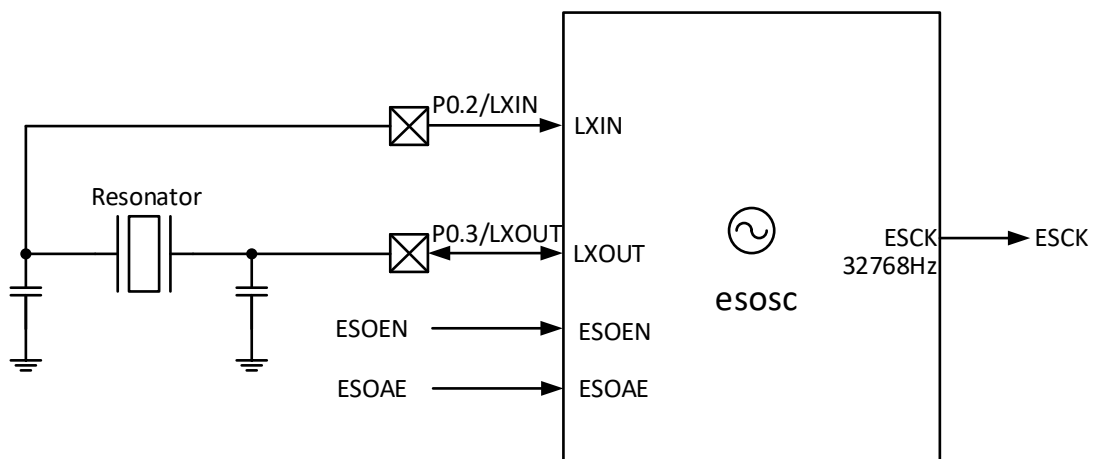


Figure 19-1 Input/Output of External Slow Clock on esosc Pin

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 $\text{RTC\_STA}[\text{ESOEN}] = 1$ and $\text{RTC\_STA}[\text{ESOAE}] = 1$.

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 $\text{CAL\_CR0}[\text{CAL\_STA}] = 1$ in software to start the calibration. Read $\text{CAL\_CR0}[\text{CAL\_BUSY}]$ flag bit to check if the calibration process is completed. When the calibration is completed ($\text{CAL\_CR0}[\text{CAL\_BUSY}] = 0$), the readout of $\text{CAL\_CR0}[\text{CAL\_ARR}]$ 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

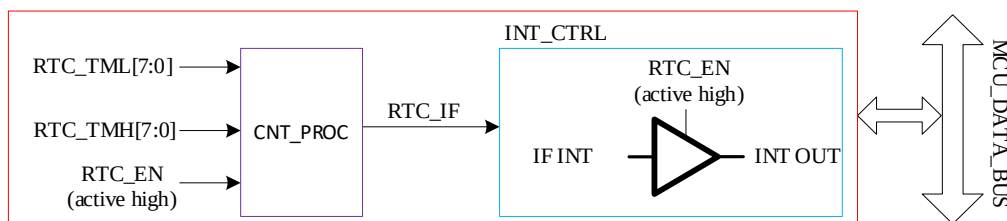


Figure 21-1 RTC Functional Block Diagram

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.
- FU6815T has up to 19 GPIO pins, including P0.0~P0.1, P1.1~P1.7, P2.1~P2.2, P2.4~P2.7, P3.0~P3.1, P3.4, and P4.7.
- 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	P4_OE[6:4]			RSV	P4_OE[2:0]		
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
[6:4]	P4_OE[6:4]	P4.4 ~ P4.6 Digital I/O Selection 0: Input 1: Output
[3]	RSV	Reserved
[2:0]	P4_OE[2:0]	P4.0 ~ P4.2 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> <tr> <th>HBMOD</th><th>P1_OE[3]</th><th>P1.3 Pin Mode</th></tr> <tr> <td>0</td><td>0</td><td>Digital Input</td></tr> <tr> <td>0</td><td>1</td><td>Digital Output</td></tr> <tr> <td>1</td><td>0</td><td>Analog Mode</td></tr> <tr> <td>1</td><td>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> </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	P4_PU[7:4]				RSV	P4_PU[2:0]		
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						
[7:4]	P4_PU[7:4]	P4.4 ~ P4.7 Pull-up Resistor Enable 0: Disable 1: Enable						
[3]	RSV	Reserved						
[2:0]	P4_PU[2:0]	P4.0 ~ P4.2 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 Function 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 Function Switching 0: No function switching, with P0.7 pin serving as output 1: Function switching, with P0.1 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 Function 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 Function 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)

Bit	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

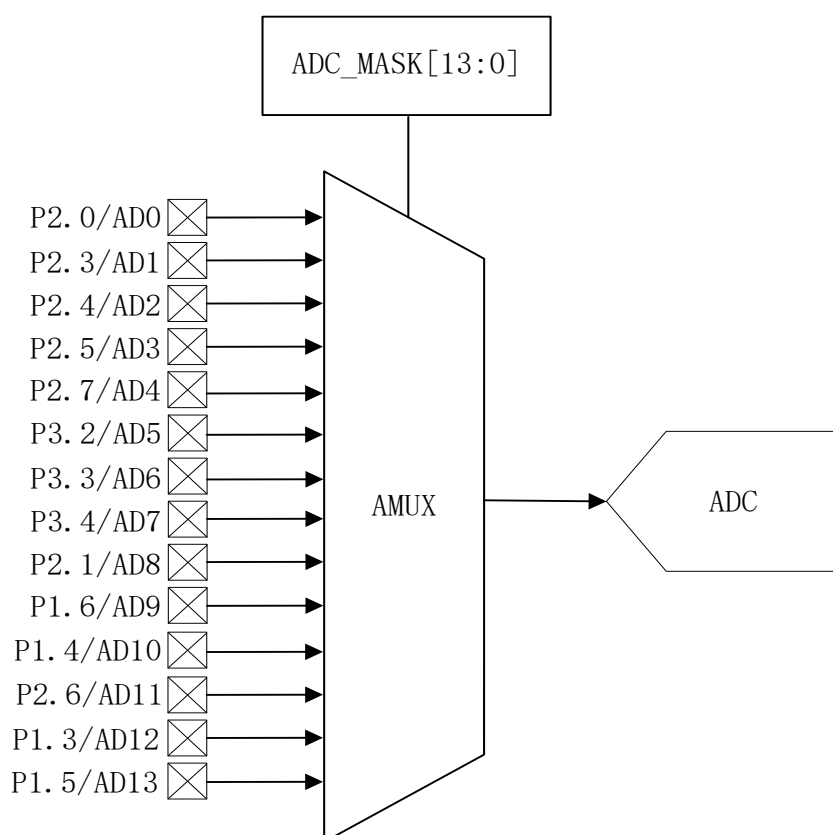


Figure 23-1 ADC Multiplexer Block Diagram

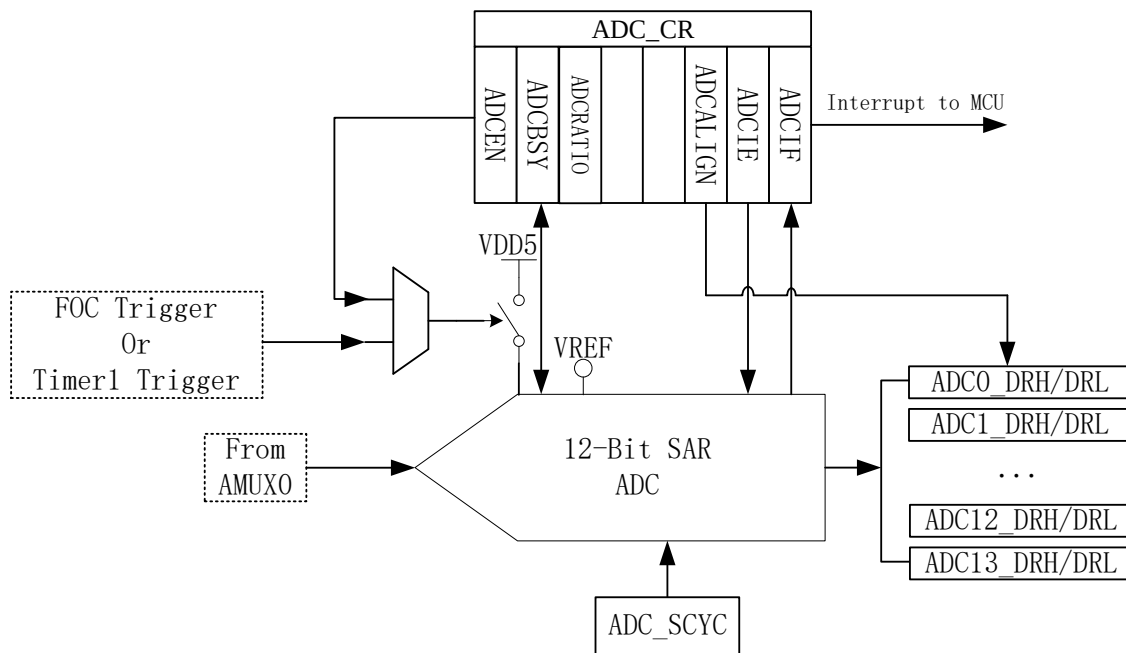


Figure 23-2 ADC Functional Block Diagram

23.3 ADC Operations

23.3.1 Sequential Sampling Mode

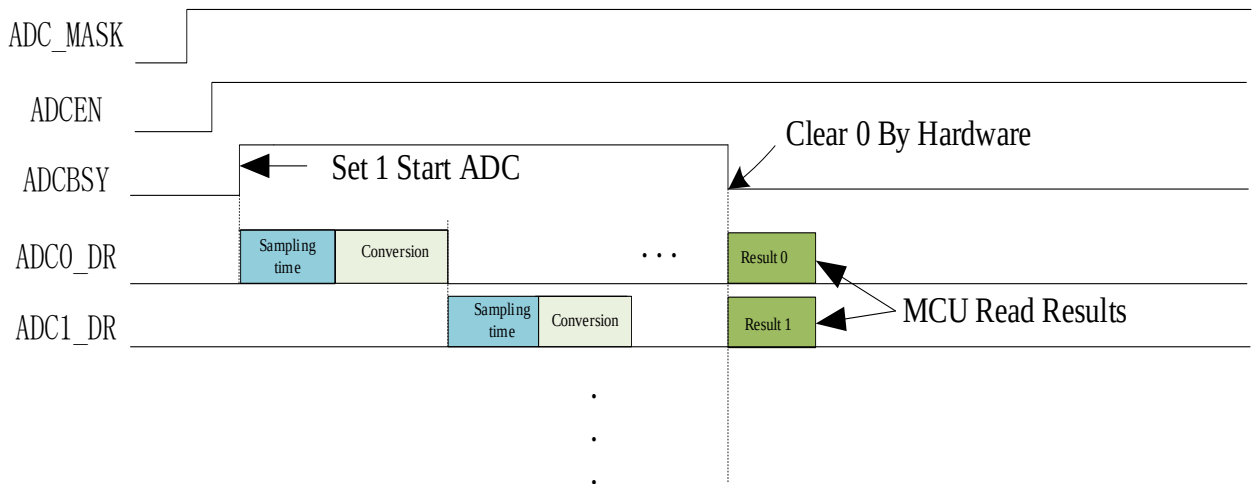


Figure 23-3 ADC Sequential Sampling Timing

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	ADCB SY	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]	ADCB SY	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	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]. Note: ADC results of Triggered Sampling Mode are not updated to this register.						

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

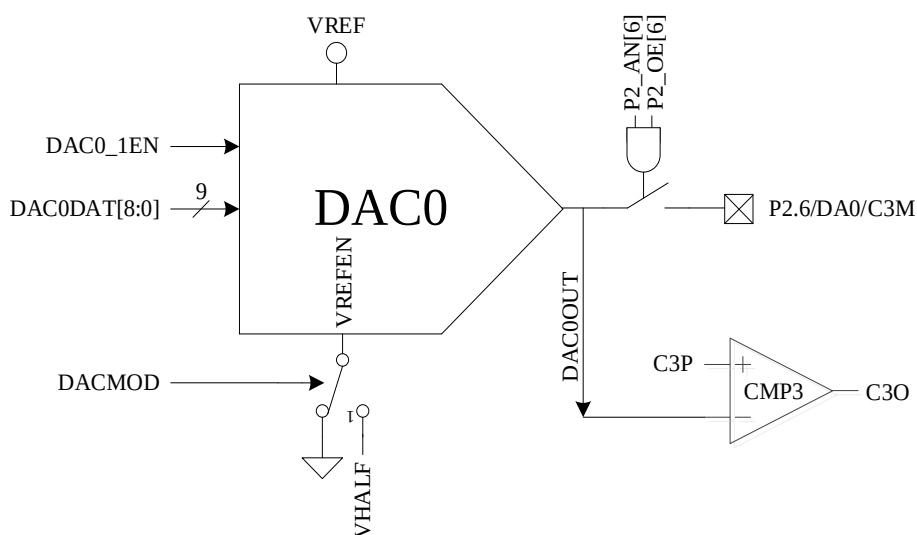


Figure 24-1 DAC0 Functional Block Diagram

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_VHALF_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~VREF. When DAC_CR[DACMOD] = 1, half-voltage output mode is active, the range of output voltage is VHALF~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

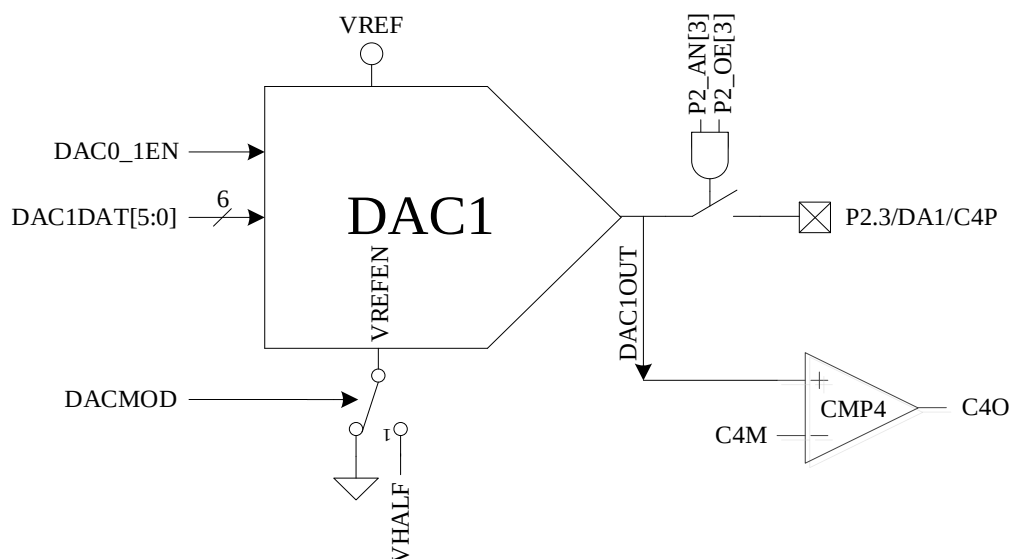


Figure 24-2 DAC1 Functional Block Diagram

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_VHALF_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

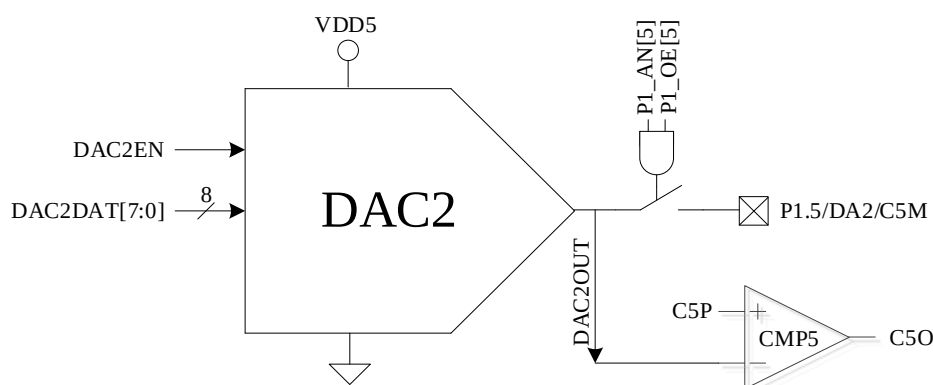


Figure 24-3 DAC2 Functional Block Diagram

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_VHALF_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

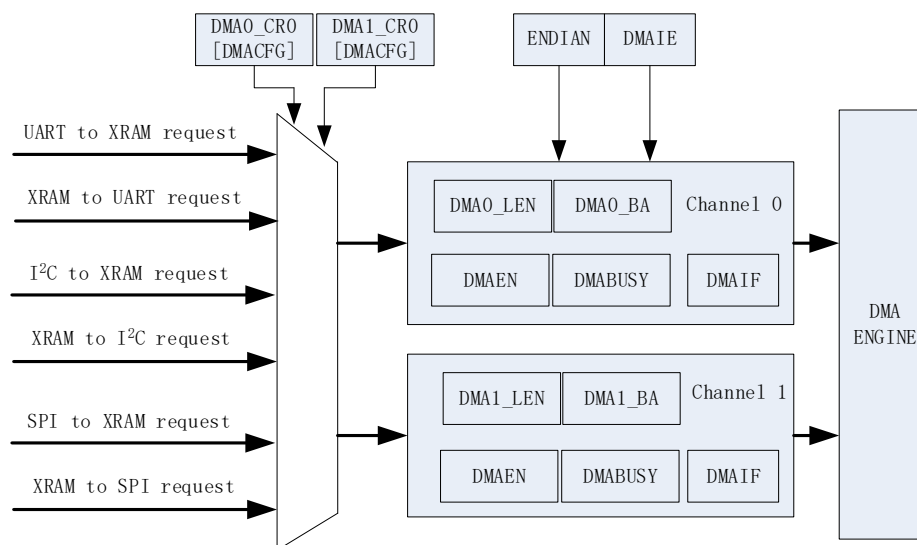


Figure 25-1 DMA Functional Block Diagram

The DMA module is a dual-channel DMA controller, which performs direct data transfer between peripherals (SPI, UART, I²C) 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 DMAx_CR0[DMACFG];
2. Configure DMA interrupt enable, transfer order, transfer length and XRAM start address. Write “1” to DMAx_CR0[DMAEN] and DMAx_CR0[DMABSY] to start DMA;
3. After data transfer, the interrupt flag bit DMAx_CR0[DMAIF] is set to “1” by hardware and it is cleared to “0” by software;
4. Set DMAx_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 ² C to XRAM 011: From XRAM to I ² 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 ² C to XRAM 011: From XRAM to I ² C						

		100: From SPI to XRAM 101: From XRAM to SPI 110: From UART2 to XRAM 111: From XRAM to UART2 Note: It cannot 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 I²C is selected as DMA channel peripherals (including from I²C to XRAM and from XRAM to I²C), START + Address interrupt of I²C communication still requires to be cleared to “0” by MCU software. In I²C slave mode, if STOP is received, I2C_SR[I2CSTP] = 0 is configured to clear I²C interrupt and restart the DMA transfer.

26 VREF

26.1 VREF Instructions

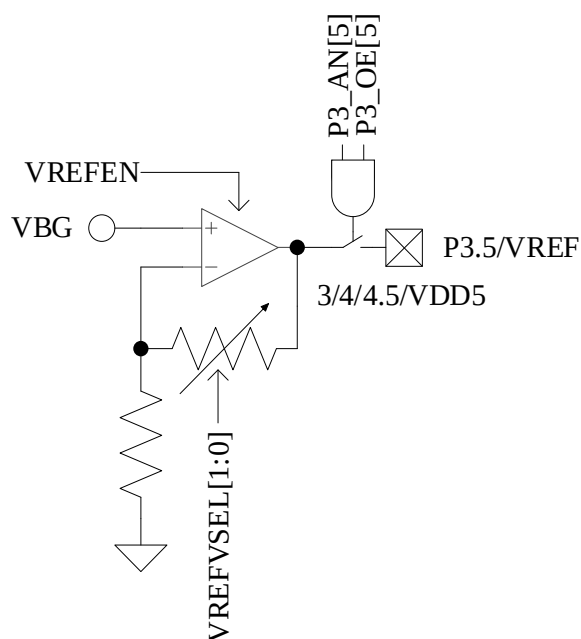


Figure 26-1 I/O Pins of VREF Module

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_VHALF_CR[VREFEN] is set to “1”. The output voltage is selected by configuring VREF_VHALF_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_VHALF_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 1μF ~ 4.7μF 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

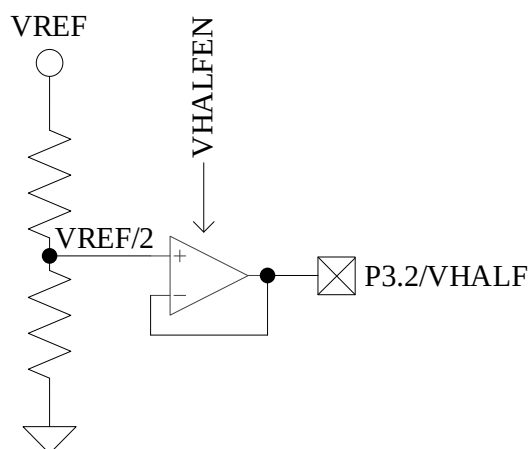


Figure 27-1 I/O Pins of VHALF Module

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_VHALF_CR[VHALFSEL]`, as detailed:
 00: $VREF/8$; 01: $VREF/4$; 10: $VREF*25/64$; 11: $VREF/2$ (Default)

VHALF is enabled when `VREF_VHALF_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_VHALF_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.

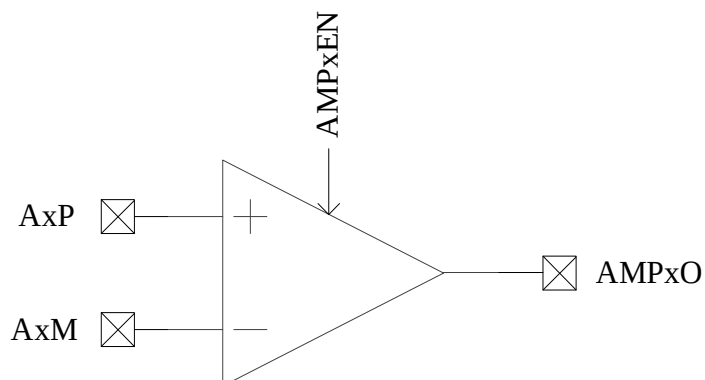


Figure 28-1 Schematic Diagram of Operational Amplifier Module

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

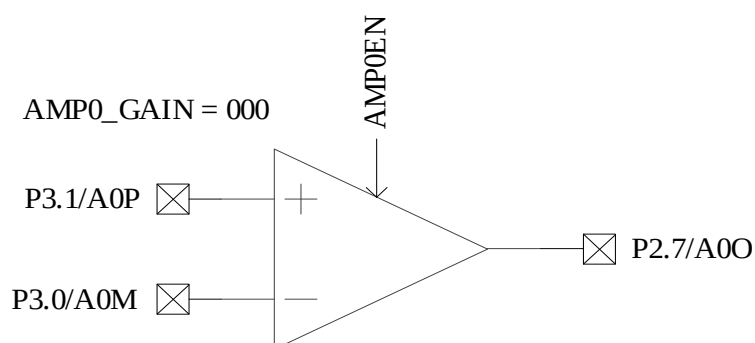


Figure 28-2 Bus Current AMP0

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

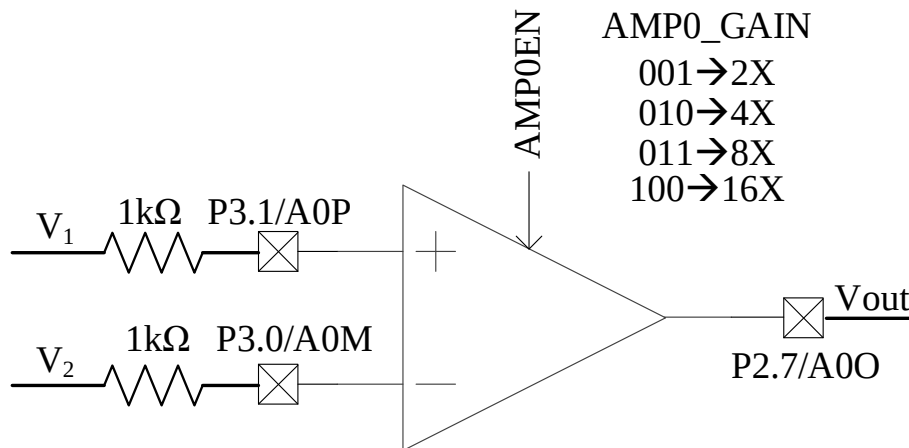


Figure 28-3 AMP0 Operating in PGA Differential Input Mode

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

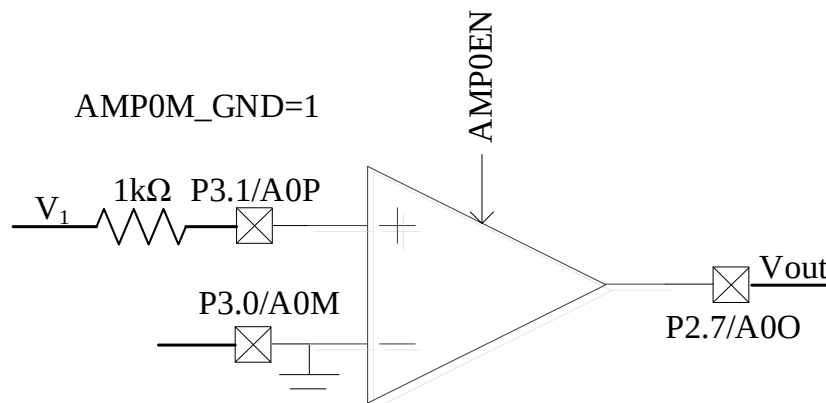


Figure 28-4 AMP0 Operating in PGA Single-ended Input Mode

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

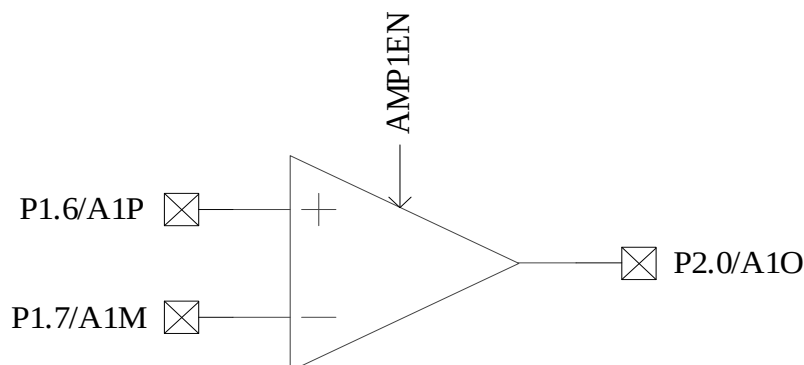


Figure 28-5 AMP1 I/O Pins

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

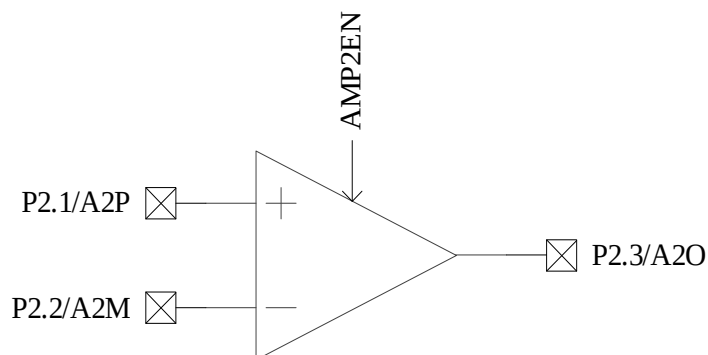


Figure 28-6 AMP2 I/O Pins

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

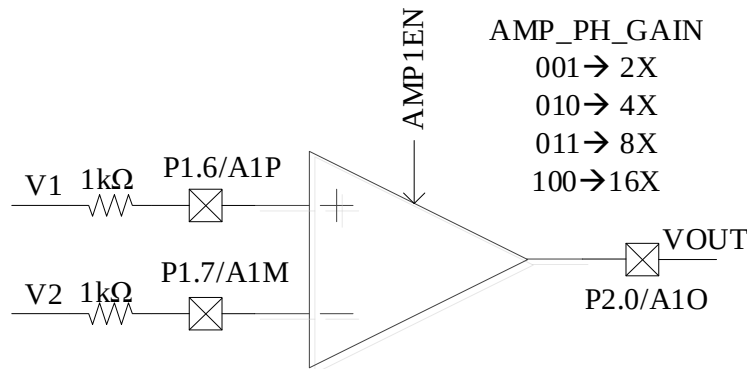


Figure 28-7 AMP1 Operating in PGA Differential Input Mode

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

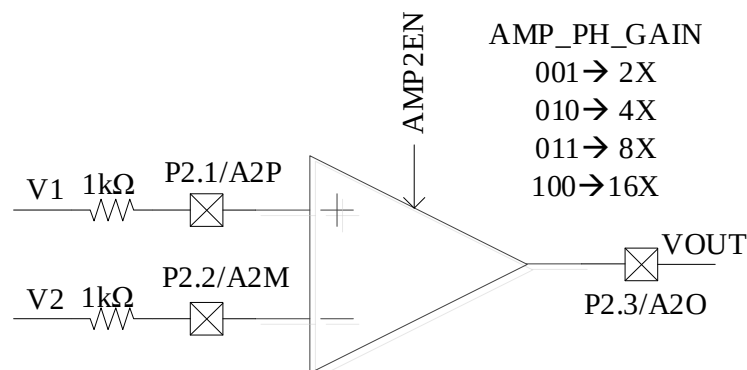


Figure 28-8 AMP2 Operating in PGA Differential Input Mode

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

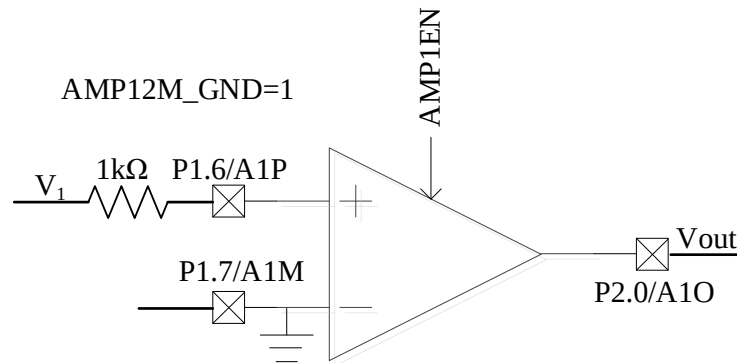


Figure 28-9 AMP1 Operating in PGA Single-ended Input Mode

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

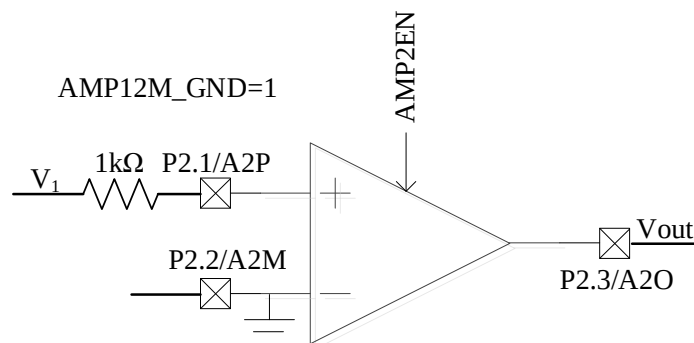


Figure 28-10 AMP2 Operating in PGA Single-ended Input Mode

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

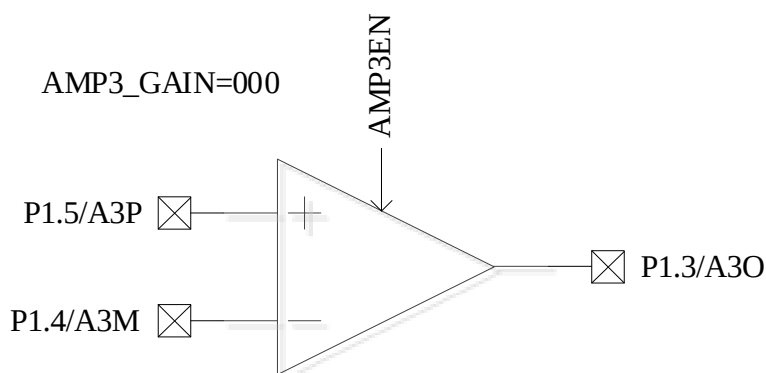


Figure 28-11 AMP3 I/O Pins

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

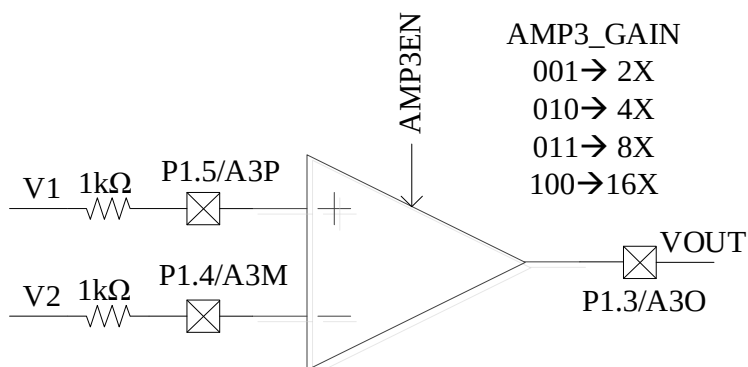


Figure 28-12 AMP3 Operating in PGA Differential Input Mode

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

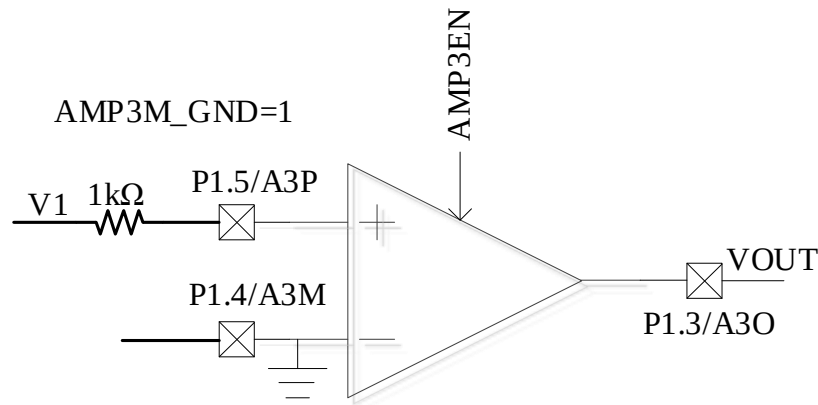


Figure 28-13 AMP3 Operating in PGA Single-ended Input Mode

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, $V_{out} = 7/6 * V_{HALF} + 7/3 * V_1$

When AMP_CR2[AMP3_GAIN] is set as 4x, $V_{out} = 6/5 * V_{HALF} + 24/5 * V_1$

When AMP_CR2[AMP3_GAIN] is set as 8x, $V_{out} = 11/9 * V_{HALF} + 88/9 * V_1$

When AMP_CR2[AMP3_GAIN] is set as 16x, $V_{out} = 21/17 * V_{HALF} + 336/17 * V_1$

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

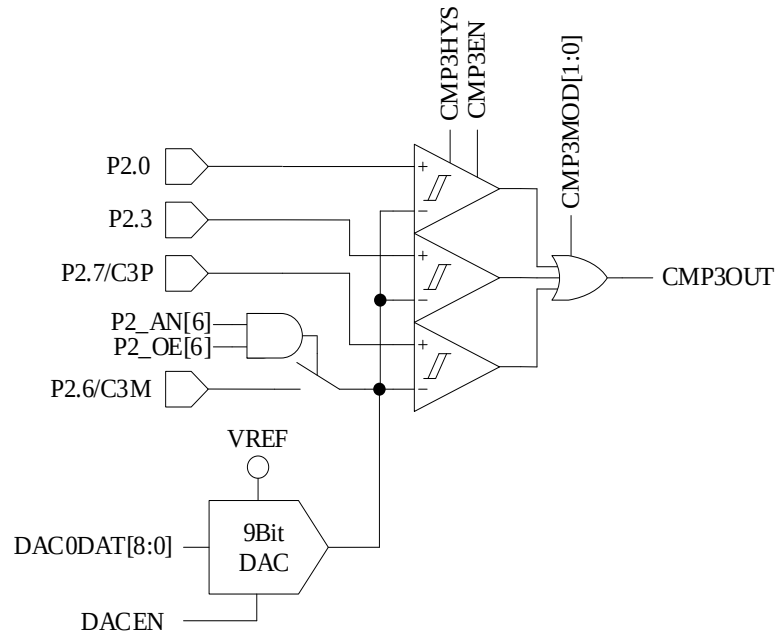


Figure 29-1 CMP3 I/O Pins

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 input the CMP3 negative signal to P2.6. 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.

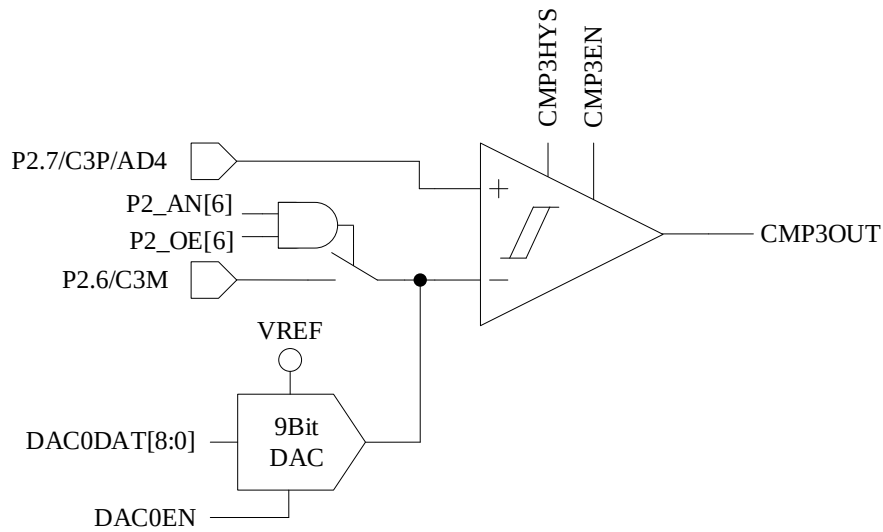


Figure 29-2 Single-comparator Input Mode

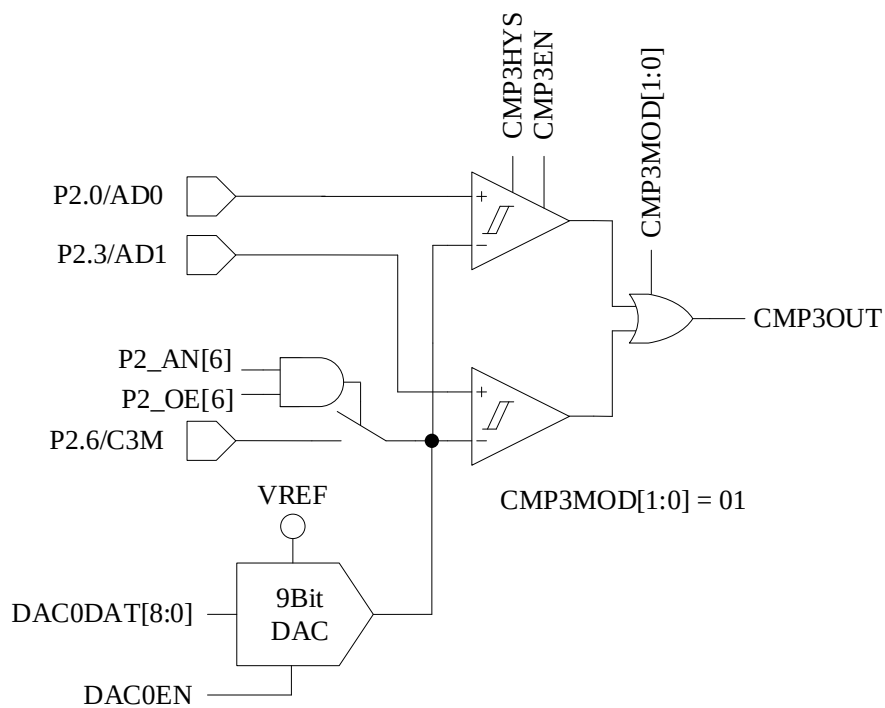


Figure 29-3 Dual-comparator Input Mode

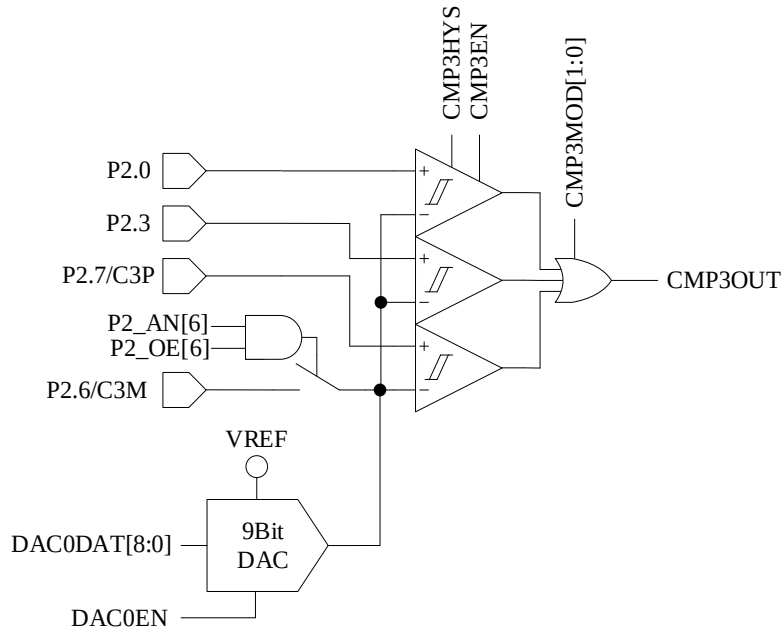


Figure 29-4 Triple-comparator Input Mode

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 μ 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 μ s to restore motor drive.

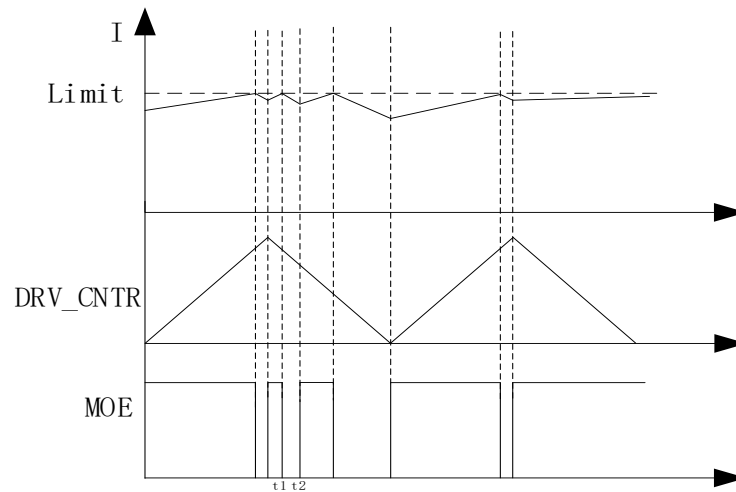


Figure 29-5 Cycle-by-cycle Current Limiting Waveform ($t_2 - t_1 = 10\mu\text{s}$) when EVT_FILT[MOEMD] = 10

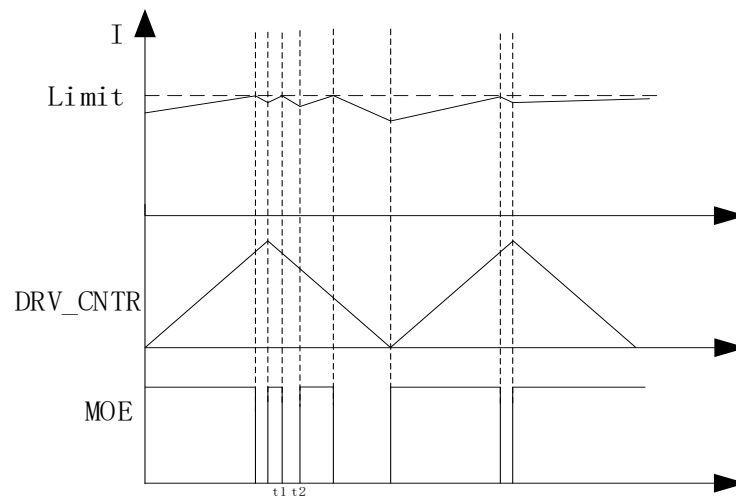


Figure 29-6 Cycle-by-cycle Current Limiting Waveform ($t_2 - t_1 = 5\mu\text{s}$) when EVT_FILT[MOEMD] = 11

29.1.2 Comparator CMP4

The input and output ports of the CMP4 are 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.

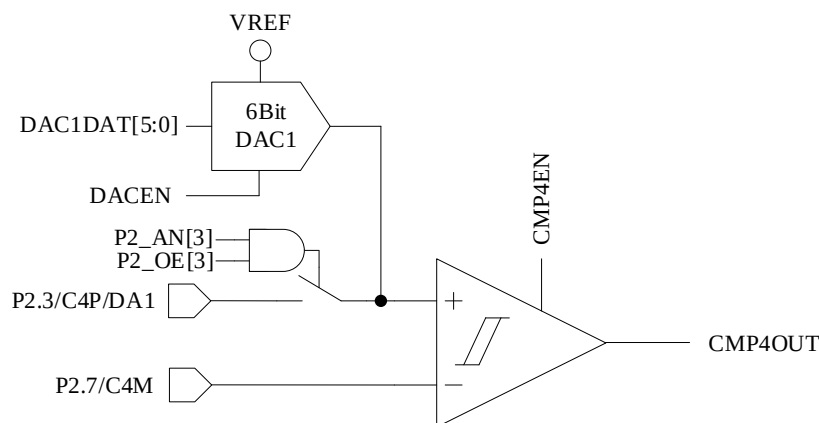


Figure 29-7 Schematic Diagram of CMP4 Module

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.

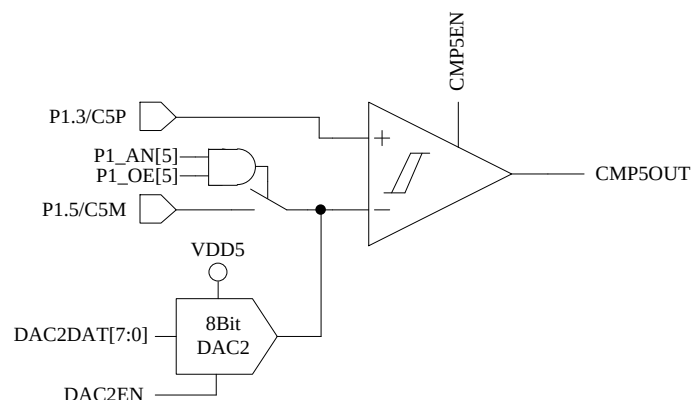


Figure 29-8 Schematic Diagram of CMP5 Module

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 $\text{CMP\_CR2}[\text{CMP0MOD}] = 00$, 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 $\text{CMP\_CR2}[\text{CMP0SEL}]$. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 00$, CMP0, CMP1 and CMP2 work simultaneously, which is the recommended configuration. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 01$, only CMP0 works. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 10$, only CMP1 works. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 11$, only CMP2 works.

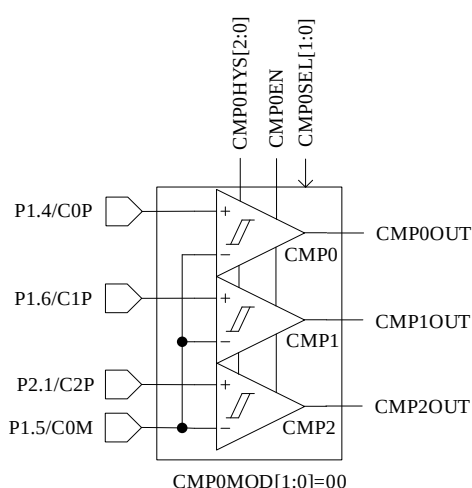


Figure 29-9 CMPG Mode with Built-in Three Comparators

(without Built-in Resistor)

When $\text{CMP\_CR2}[\text{CMP0MOD}] = 01$, 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 $\text{CMP\_CR4}[\text{CMP0FS}]$. The number of comparators operating in this mode is defined by $\text{CMP\_CR2}[\text{CMP0SEL}]$. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 00$, CMP0, CMP1 and CMP2 work simultaneously, which is the recommended configuration. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 01$, only CMP0 works. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 10$, only CMP1 works. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 11$, only CMP2 works.

When $\text{CMP\_CR4}[\text{CMP0FS}] = 0$, 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.

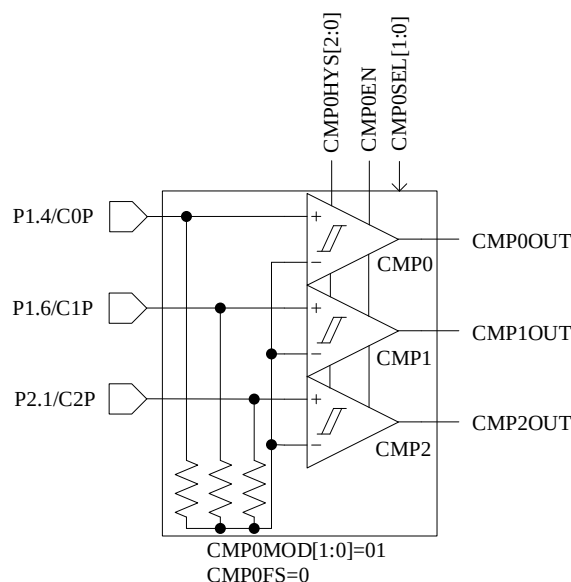


Figure 29-10 CMPG Mode with Built-in Three Comparators and Resistors

(without Function Switching)

When $\text{CMP\_CR4}[\text{CMP0FS}] = 1$, 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.

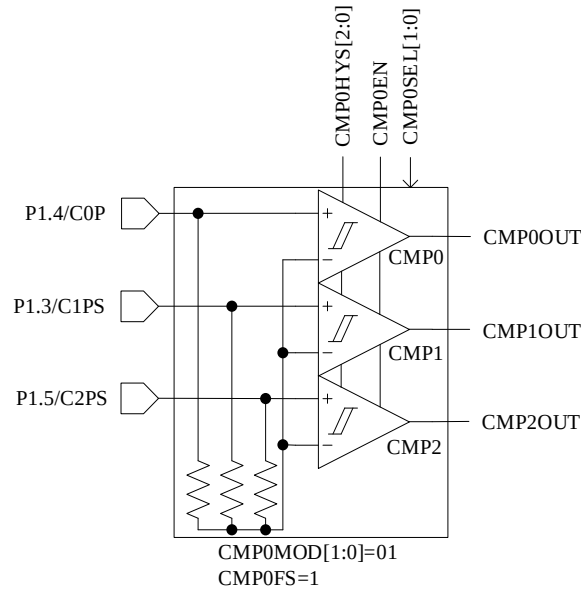


Figure 29-11 CMPG Mode with Built-in Three Comparators (with Function Switching)

When $\text{CMP\_CR2}[\text{CMP0MOD}] = 10$, 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 $\text{CMP\_CR2}[\text{CMP0SEL}]$. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 00$, CMP0, CMP1 and CMP2 work simultaneously, which is the recommended configuration. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 01$, only CMP0 works. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 10$, only CMP1 works. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 11$, only CMP2 works.

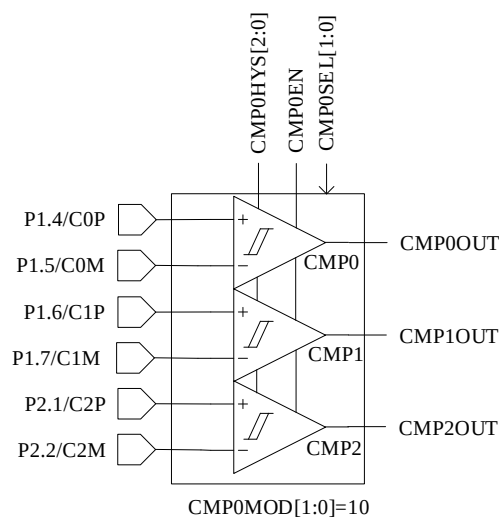


Figure 29-12 CMPG Mode with Three Differential Comparators

When $\text{CMP\_CR2}[\text{CMP0MOD}] = 11$, 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 $\text{CMP\_CR2}[\text{CMP0SEL}]$. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 00$, CMP0 and CMP1 work simultaneously, which is the recommended configuration. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 01$, only CMP0 works. When $\text{CMP\_CR2}[\text{CMP0SEL}] = 10$, only CMP1 works.

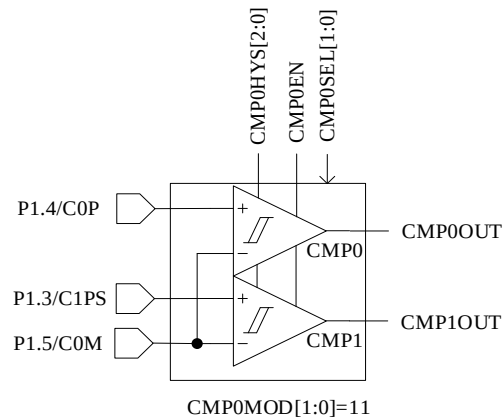


Figure 29-13 CMPG Mode with Two Comparators

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.

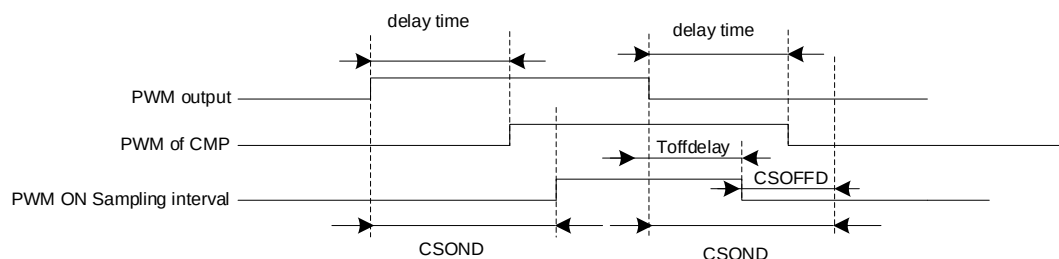


Figure 29-14 PWM ON Sampling Mode

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 IC, 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 avoid ringing at the switch node on power IC. 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.

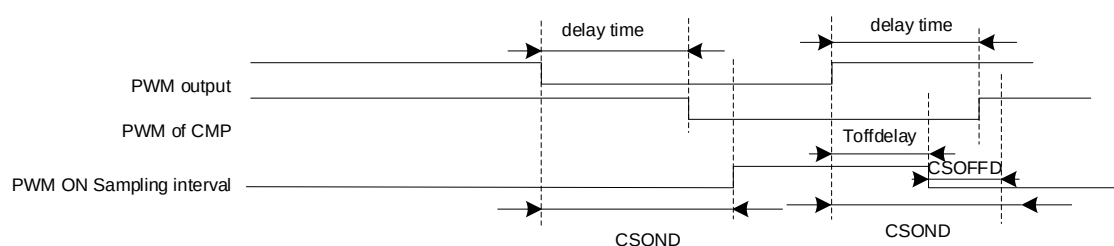


Figure 29-15 PWM OFF Sampling Mode

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 011: +6mV 100: ±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	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.						
		Table 29-1 Function Description of CMPG Port and CMP_CR2[CMP0MOD] Combination						
		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 C0M. 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 the 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 13.1.9.3 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	CMP0/CMP1/CMP2 ON-delayed Sampling Time 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]. CMP_CR4[FAEN] = 0: ON-delayed sampling time = 8 * CMP_SAMR[CSOND] * T CMP_CR4[FAEN] = 1: ON-delayed sampling time = 32 * CMP_SAMR[CSOND] * T Notes: ■ CMP_SAMR[CSOND] must be greater than or equal to CMP_SAMR[CSOFFD]. ■ See section Sampling for BLDC drive application. ■ See section RSD Comparator Sampling for RSD application.						
[3:0]	CSOFFD	CMP0/CMP1/CMP2 OFF-lead Sampling Time 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]. CMP_CR4[FAEN] = 0: OFF-lead sampling time = 8 * CMP_SAMR[CSOFFD] * T CMP_CR4[FAEN] = 1: OFF-lead sampling time = 32 * CMP_SAMR[CSOFFD] * T Notes: ■ CMP_SAMR[CSOND] must be greater than or equal to CMP_SAMR[CSOFFD]. ■ See section Sampling for BLDC drive application. ■ See section RSD Comparator Sampling for RSD application.						

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 μ s (for square-wave drive). 11: MOE is automatically cleared and enabled automatically upon Driver timer overflow/underflow events or after 5 μ 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

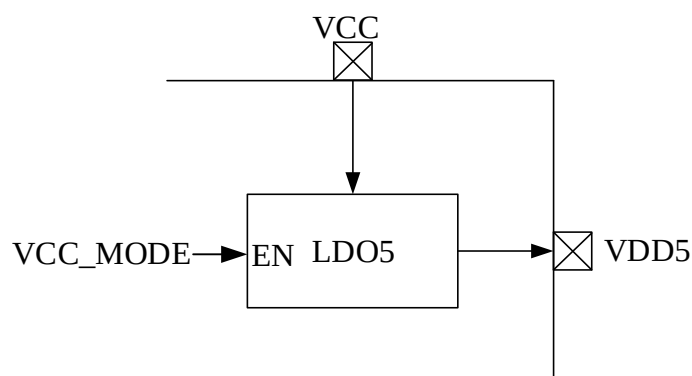


Figure 30-1 Functional Block Diagram of Power Supply

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.

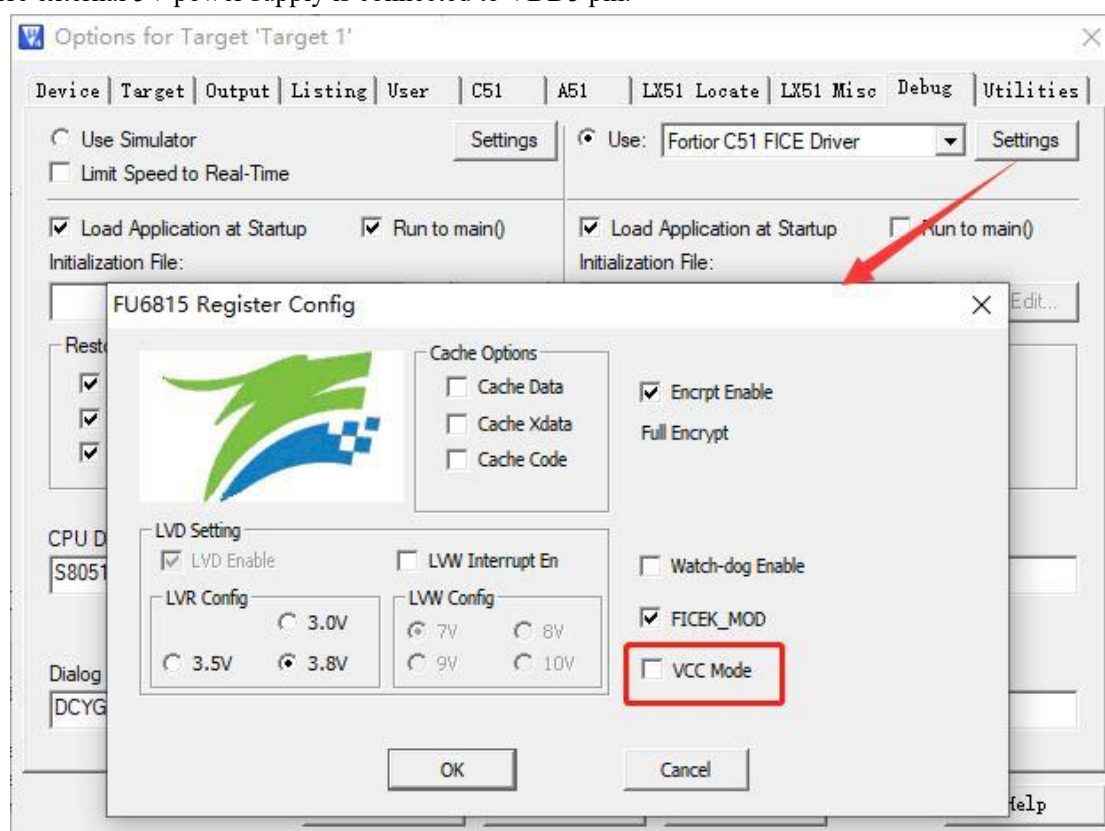


Figure 30-2 VCC_MODE Configurations

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

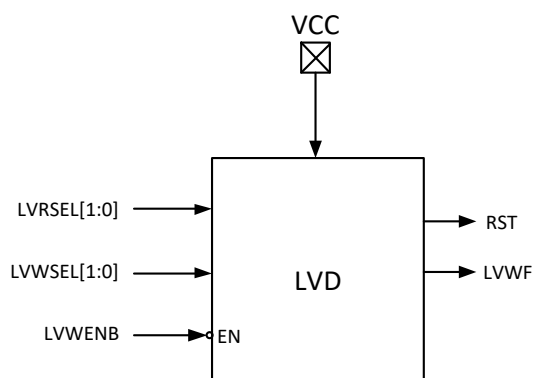


Figure 30-3 LV Detection Module

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.

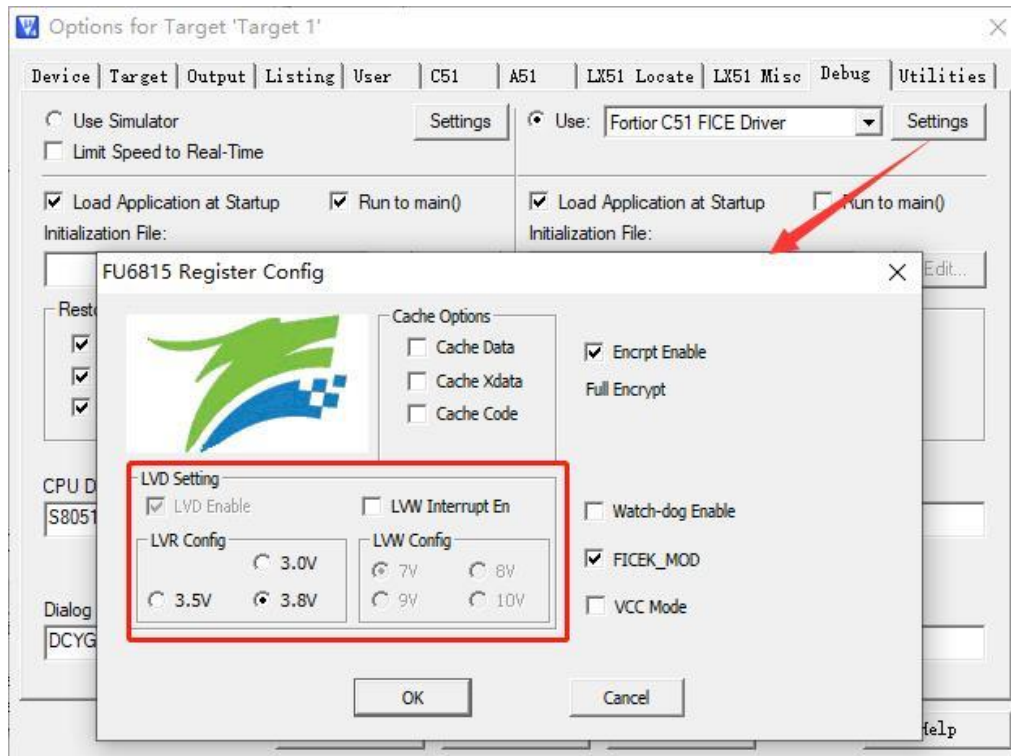


Figure 30-4 Configurations of LV Warning Threshold, LV Interrupt and LV Reset Threshold

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

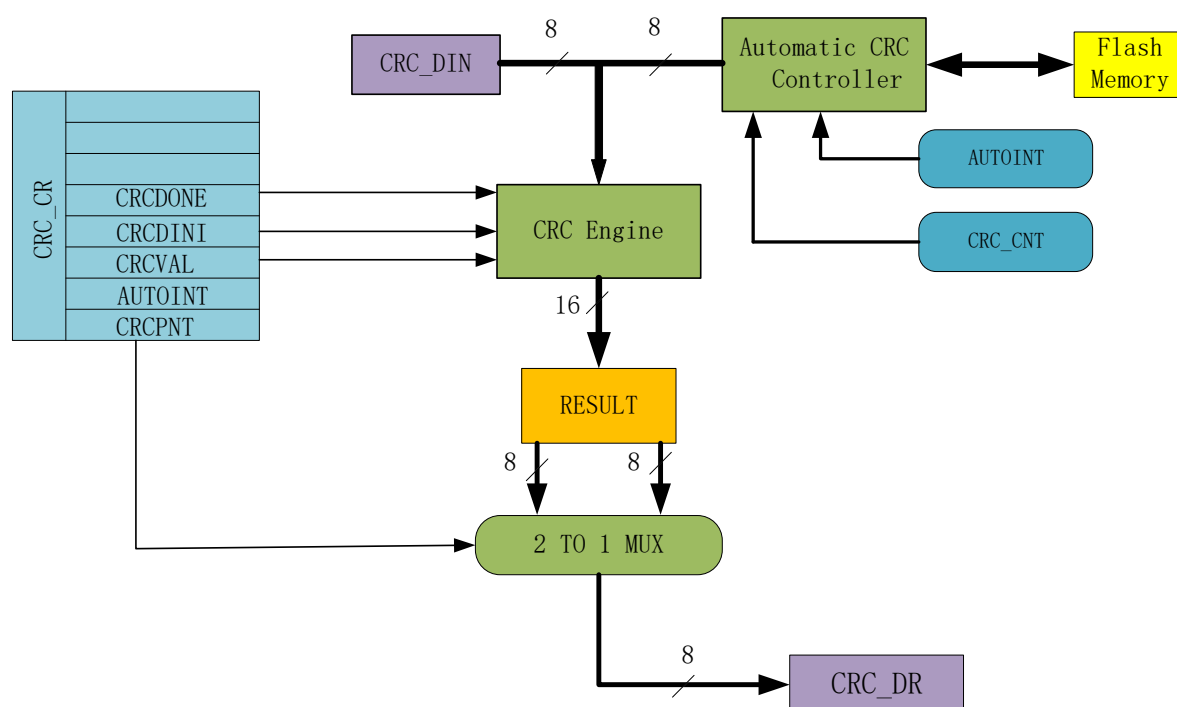


Figure 32-1 CRC Functional Block Diagram

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

CRC Criteria	Polynomial	Hexadecimal Representation
CRC16/ CCITT-FALSE	$x^{16}+x^{12}+x^5+1$	0x1021

32.2 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.

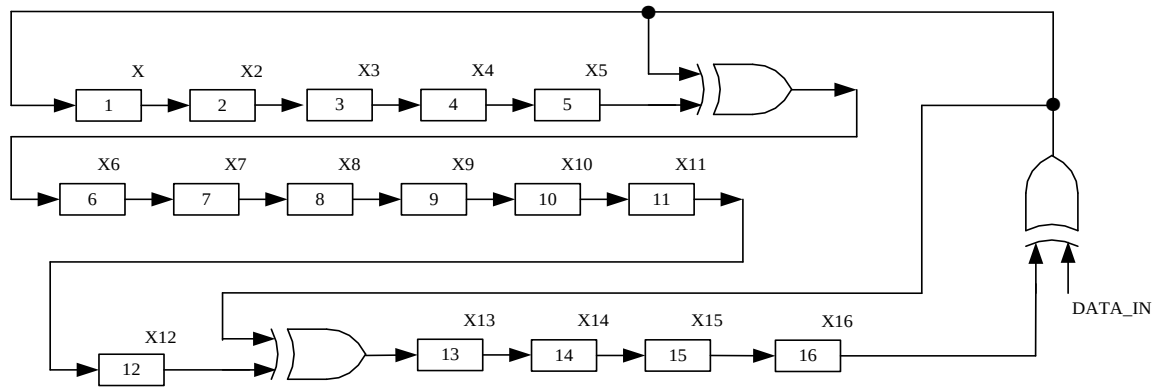


Figure 32-2 CRC16 Schematic Diagram

32.3 CRC Operations

32.3.1 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.

32.3.2 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.

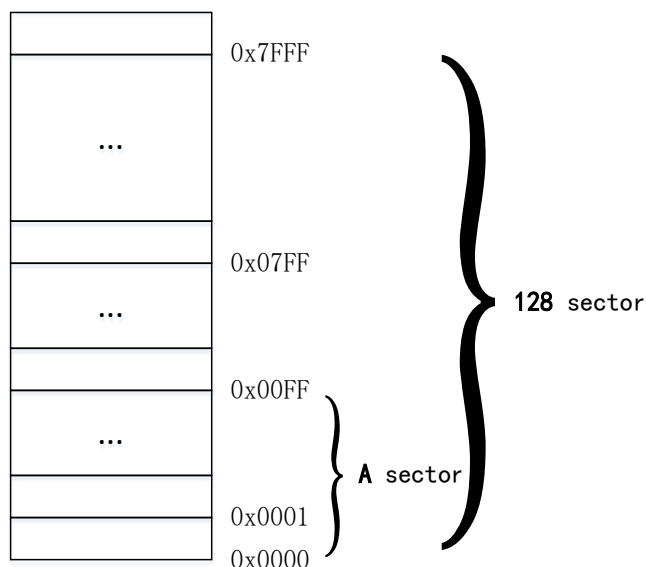


Figure 32-3 ROM Sectors

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.

32.4 CRC Registers

32.4.1 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_CR 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.

32.4.2 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.						

32.4.3 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.						

32.4.4 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.						

32.4.5 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

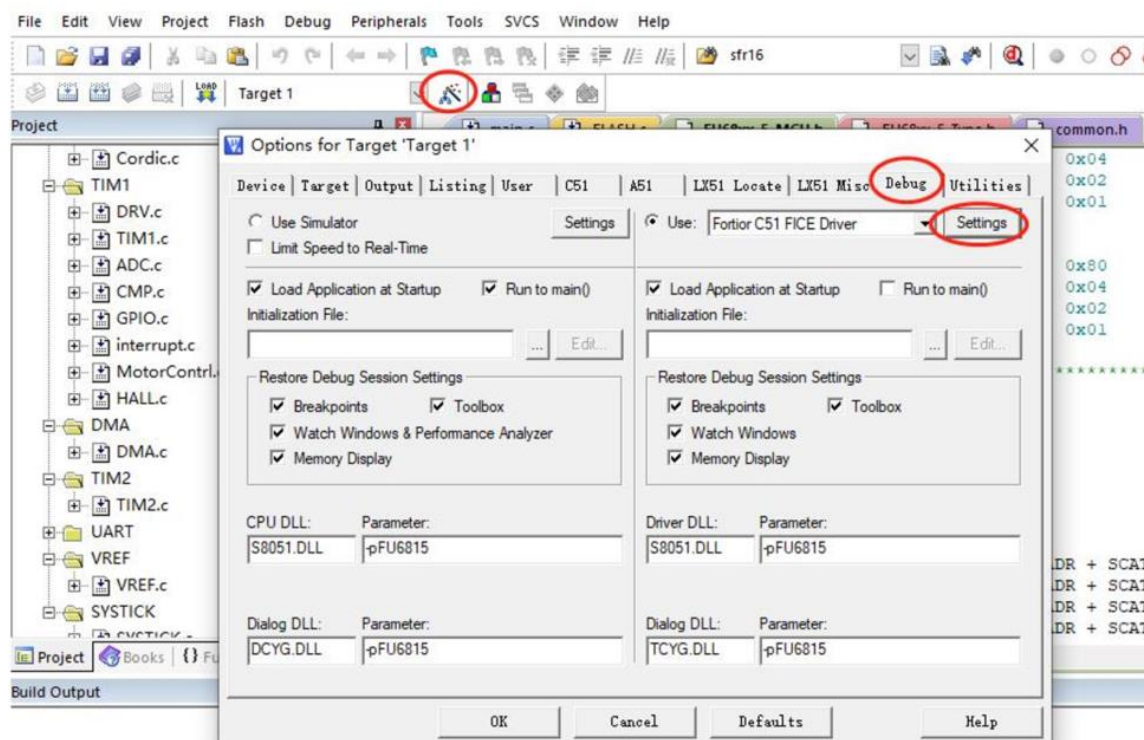


Figure 34-1 Code Protection Configurations

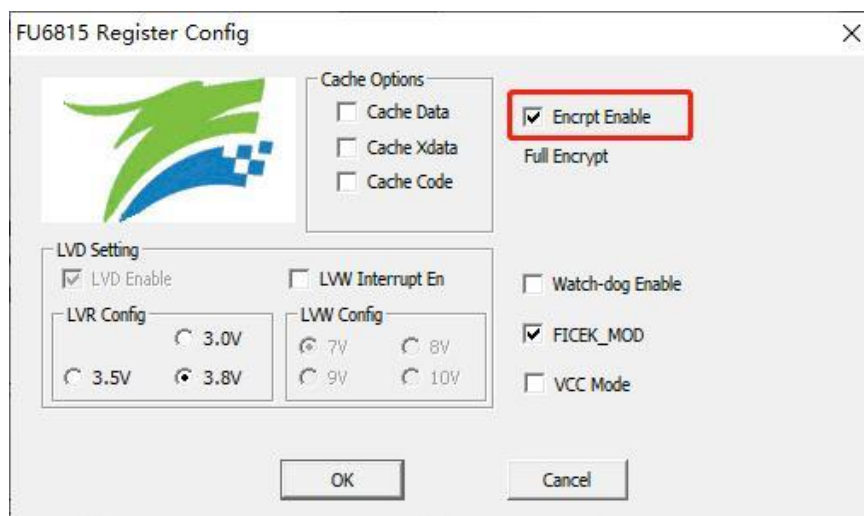


Figure 34-2 Full Code Protection Mode

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

Rev.	Description	Date	Prepared By
V2.0	First release. Translated from Chinese version 2.0.	2023/07/12	Eric Deng
V3.0	- Added the chip FU6864L; - Updated IO Type and descriptions on RXD2S2, RXD2, RXD2S, RXD and RXDS pins; - Updated Figure 35-1 LQFP48_7X7 Package Drawings and Dimensions; - Updated Figure 35-2 QFN56_7X7 Package Drawings and Dimensions; - Deselected “External Slow Clock” for FU6864Q in section 4 Ordering Information; - 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; - Added section 19 Clock and moved section 20.4 Clock Calibration to section 19; - Modified figures and descriptions on PGA single-ended input mode of AMP0/AMP1/AMP2/AMP3; - Standardized document format.	2023/10/18	Eric Deng
V3.1	- Modified descriptions on Timer2 for FU6815L/FU6865Q in section 1.1 Features; - Added OLDBGS feature and its description to P0.0; - Modified typical value of VDD18 “1.8V” as “1.85V” in Table 2-1 FU6815L LQFP48 Pin Descriptions; - Updated chapter 3 Package Information; - Added “Operating Ambient Temperature T_A” ($V_{CC} \leq 15V$ & $I_{vcc} \leq 30mA$) and Note [4] in section 5.2 Global Electrical Characteristics; - Added “Operating Ambient Temperature T_A” in Table 5-5 Global Electrical Characteristics of FU6815L and Table 5-6 Global Electrical Characteristics of FU6865Q; - Modified the description “Choose ADC Channel 6 when PFC is enabled...” on bit [7:4] in section 12.2.4 PFC_ADCCH (0x40E1) as “Choose ADC Channel 12 when PFC is enabled...”; - Modified “IAC_UKMINH(0x40E4)” as “IAC_UKMINH(0x40FE)” in section 12.2.21 IAC_UKMIN (0x40FE, 0x40FF); - Modified “FOC_THETA” and “FOC_RTHESTEP” in section 13.1.9.2 Forced Pulling Angle as “FOC__THETA” and “FOC__RTHESTEP” respectively; - Modified the type “W” in section 13.2.33 FOC__VALP (0x40C4, 0x40C5) as “R”; - Modified “TIM1__KR” and “TIM1__KF” as “TIM1_KR” and “TIM1_KF” respectively; - Modified “TIM2_CNTR”, “TIM2_DR” and “TIM2_ARR” as “TIM2__CNTR”, “TIM2__DR” and “TIM2__ARR” respectively; - Added the chip model FU6864Q/FU6864L to section 18.1.4 6N Pre-driver Mode; - Deleted “P3_AN[2]” in Figure 27-1 I/O Pins of VHALF Module; - Modified the sentence “CMP4 is a hysteresis comparator, as shown in Figure 29-7.” in section 29.1.2 Comparator CMP4 as “The input and output ports of the CMP4 are shown in Figure 29-7.”; - Standardized document format.	2024/01/31	Eric Deng

Rev.	Description	Date	Prepared By
V4.0	1. Added model FU6815T; 2. 1.1 added “FU6815L: PFC”; 3. Added “1-wire” description to P0.0 OLDBGS in pin descriptions; 4. Modified VDD5 pin description of FU6865Q QFN56; 5. Modified 2.10 FU6864L LQFP52 Pinout Diagram; 6. Modified “MIPS” to “Clock Frequency (MHz)” in 4 Ordering Information; 7. Added parameters of “V_{BU}, V_{BV}, V_{BW}” and “V_{SU}, V_{SV}, V_{SW}” to Table 5-19 6N Pre-driver IO Electrical Characteristics of FU6864Q and Table 5-20 6N Pre-driver IO Electrical Characteristics of FU6864L; 8. Added footnote “[2]” to 5.8 Operational Amplifier Electrical Characteristics; 9. Modified monitor voltage “VDD” to “VCC” in section 6.4 Low Voltage Detector Reset; 10. Modified Figure 12-6 Diagram of PWM Output and IAC/UAC Sampling and added descriptions; 11. Modified “Using ADC Channel 6” to “Using ADC Channel 12” in 12.1.8.2 IAC Sampling; 12. Modified diagrams in chapter 13, 14, 15, 16, 18, and 29; 13. Modified “0.1μF ~ 1μF” to “1μF ~ 4.7μF” of “[4]” in 26.2.1 VREF_CR (0x404F); 14. Modified “Configure P2_AN[6] and P2_OE[6] to “1” to enable VREF on the negative input of CMP3” to “Configure P2_AN[6] and P2_OE[6] to “1” to input the CMP3 negative signal to P2.6” in section 29.1.1; 15. Modified Table 32-1; 16. Deleted section 32.2.	2024/11/29	Freya Fu

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