



# HT32F65432A

## Datasheet

**32-Bit Arm® Cortex®-M0+ BLDC Microcontroller  
with 3-channel 36 V P/N Gate-Driver,  
32 KB Flash and 4 KB SRAM with 2 Msps ADC,  
CMP, OPA, USART, UART, SPI, I<sup>2</sup>C, MCTM, GPTM,  
SCTM, BFTM, CRC, LSTM, WDT, DIV and PDMA**

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# 1 General Description

The Holtek HT32F65432A device is a high performance, low power consumption 32-bit microcontroller based around an Arm® Cortex®-M0+ processor core. The Cortex®-M0+ is a next-generation processor core which is tightly coupled with Nested Vectored Interrupt Controller (NVIC), SysTick timer and advanced debug support.

The device operates at a frequency of up to 60 MHz with a Flash accelerator to obtain maximum efficiency. It provides 32 KB of embedded Flash memory for code/data storage and 4 KB of embedded SRAM memory for system operation and application program usage. A variety of peripherals, such as Hardware Divider DIV, ADC, OPA, CMP, I<sup>2</sup>C, USART, UART, SPI, MCTM, GPTM, SCTM, BFTM, CRC-16/32, LSTM, WDT, PDMA, SW-DP (Serial Wire Debug Port), etc., are also implemented in the device. Several power saving modes provide the flexibility for maximum optimization between wakeup latency and power consumption, an especially important consideration in low power applications.

The device also includes a gate-driver for 3-phase motor driving applications. The gate-driver has several internal protection functions and provides an integrated 5 V low quiescent current LDO which can provide power supply.

The above features ensure that the device is suitable for use in a wide range of applications, especially in areas such as low voltage ceiling fans, exhaust fans, electric shavers, pumps, fans and so on.

**arm** CORTEX

## 2 Features

### Core

- 32-bit Arm® Cortex®-M0+ processor core
- Up to 60 MHz operating frequency
- Single-cycle multiplication
- Integrated Nested Vectored Interrupt Controller (NVIC)
- 24-bit SysTick timer

The Cortex®-M0+ processor is a very low gate count, highly energy efficient processor that is intended for microcontroller and deeply embedded applications that require an area optimized, low-power processor. The processor is based on the ARMv6-M architecture and supports Thumb® instruction sets, single-cycle I/O ports, hardware multiplier and low latency interrupt respond time.

### On-Chip Memory

- 32 KB on-chip Flash memory for instruction/data and option byte storage
- 4 KB on-chip SRAM
- Supports multiple booting modes

The Arm® Cortex®-M0+ processor access and debug access share the single external interface to external AHB peripherals. The processor access takes priority over debug access. The maximum address range of the Cortex®-M0+ is 4 GB since it has a 32-bit bus address width. Additionally, a pre-defined memory map is provided by the Cortex®-M0+ processor to reduce the software complexity of repeated implementation by different device vendors. However, some regions are used by the Arm® Cortex®-M0+ system peripherals. Refer to the Arm® Cortex®-M0+ Technical Reference Manual for more information. Figure 2 in the Overview chapter shows the memory map of the HT32F65432A device, including code, SRAM, peripheral and other pre-defined regions.

### Flash Memory Controller – FMC

- Flash accelerator to obtain maximum efficiency
- 32-bit word programming with In System Programming (ISP) and In Application Programming (IAP)
- Flash protection capability to prevent illegal access

The Flash Memory Controller, FMC, provides all the necessary functions and pre-fetch buffer for the embedded on-chip Flash Memory. Since the access speed of the Flash Memory is slower than the CPU, a wide access interface with a pre-fetch buffer is provided for the Flash Memory in order to reduce the CPU waiting time which will cause CPU instruction execution delays. Flash Memory word programming/page erase functions are also provided.

### Reset Control Unit – RSTCU

- Supply supervisor
  - Power On Reset / Power Down Reset – POR / PDR
  - Brown-Out Detector – BOD
  - Programmable Low Voltage Detector – LVD

The Reset Control Unit, RSTCU, has three kinds of reset, a power on reset, a system reset and an APB unit reset. The power on reset, known as a cold reset, resets the full system during power up. A system reset resets the processor core and peripheral IP components with the exception of the SW-DP controller. The resets can be triggered by external signals, internal events and the reset generators.

## Clock Control Unit – CKCU

- External 4 to 16 MHz crystal oscillator
- Internal 8 MHz RC oscillator trimmed to  $\pm 2\%$  accuracy at 5.0 V operating voltage and 25 °C operating temperature
- Internal 32 kHz RC oscillator
- Integrated system clock PLL
- Independent clock divider and gating bits for peripheral clock sources

The Clock Control Unit, CKCU, provides a range of oscillator and clock functions. These include High Speed Internal RC oscillator (HSI), High Speed External crystal oscillator (HSE), Low Speed Internal RC oscillator (LSI), Phase Lock Loop (PLL), HSE clock monitor, clock prescaler, clock multiplexer, APB clock divider and gating circuitry. The clocks of AHB, APB and Cortex®-M0+ are derived from system clock (CK\_SYS) which can come from HSI, HSE, LSI or system PLL. Watchdog Timer (WDT) and Low Speed Timer (LSTM) use the LSI as their clock source.

## Power Management Control Unit – PWRCU

- $V_{DD}$  power supply: 2.5 V to 5.5 V
- Integrated 1.5 V LDO regulator for MCU core, peripherals and memories power supply
- $V_{DD}$  and  $V_{CORE}$  power domains
- Two power saving modes: Sleep and Deep-Sleep modes

Power consumption can be regarded as one of the most important issues for many embedded system applications. Accordingly the Power Control Unit, PWRCU, in the device provides two types of power saving modes which are the Sleep and Deep-Sleep modes. These operating modes reduce the power consumption and allow the application to achieve the best trade-off between the conflicting demands of CPU operating time, speed and power consumption.

## Gate-Driver

- Wide power supply range:  $V_{CC} = 6\text{ V} \sim 32\text{ V}$
- Maximum motor sustainable voltage up to 36 V
- 3-channel half-bridge gate-driver: drive 3 high-side P-type MOSFETs and 3 low-side N-type MOSFETs
- Integrated 5 V LDO regulator ( $V_{REG}$ ) with 50 mA output drive current
- Low sleep current:  $\leq 1\ \mu\text{A}$  ( $V_{REG} = 0\text{ V}$ )
- Support clamping voltage of  $|12V_{GS}|$  when high-side P-type MOSFETs and low-side N-type MOSFETs are conducted
- Integrated 120 ns fixed dead time control
- Support external signal wake-up, implementing ultra-low power consumption when gate-driver in the SLEEP mode
- FG high-voltage open-drain output, providing motor speed information
- High-side and low-side gate-driver control
  - High-side: High active ( $\overline{INHx}$ )
  - Low-side: Low active ( $\overline{INLx}$ )

- Protection Features
  - V<sub>CC</sub> Power Supply Input Under Voltage Lock-Out (VCC\_UVLO)
  - 5 V LDO Output Under Voltage Lock-Out (VREG\_UVLO)

## External Interrupt/Event Controller – EXTI

- Up to 16 EXTI lines with configurable trigger source and type
- All GPIO pins can be selected as EXTI trigger source
- Source trigger type includes high level, low level, negative edge, positive edge or both edges
- Individual interrupt enable, wakeup enable and status bits for each EXTI line
- Software interrupt trigger mode for each EXTI line
- Integrated deglitch filter for short pulse blocking

The External Interrupt/Event Controller, EXTI, comprises 16 edge detectors which can generate wake-up events or interrupt requests independently. Each EXTI line can also be masked independently.

## Analog to Digital Converter – ADC

- 12-bit SAR ADC engine
- Up to 2 Msps conversion rate
- Up to 12 external analog input channels

A 12-bit multi-channel Analog to Digital Converter is integrated in the device. There are multiplexed channels, which include 12 external channels on which the external analog signal can be supplied and 3 internal channels. If the input voltage is required to remain within a specific threshold window, the ADC analog watchdog function will monitor and detect the signal. An interrupt will then be generated to inform the device that the input voltage is higher or lower than the set thresholds. There are three conversion modes to convert an analog signal to digital data. The A/D conversion can be operated in one shot, continuous and discontinuous conversion modes.

## Operational Amplifier – OPA

- Fixed dedicated I/O pins
- Internal output paths to the A/D converter or comparator
- Input offset calibration
- 10-bit DAC offset voltage

## Comparator – CMP

- Two rail-to-rail comparators
- Each comparator has configurable inverting or non-inverting inputs used for flexible voltage selection
  - Dedicated I/O pins
  - Internal voltage reference provided by 8-bit scaler – CMP0 only
  - Internal operational amplifier output
- Programmable hysteresis
- Programmable response speed and power consumption
- Comparator output can be routed to I/O pin or to multiple timers or ADC trigger input
- 8-bit scaler can be configured to dedicated I/O for voltage reference
- Configurable inverting input from CMP0N, CMP1N or CVREF

- Interrupt generation capability with wakeup from Sleep or Deep Sleep mode through the EXTI controller

Two general purpose comparators are implemented within the device. They can be configured either as standalone comparators or combined with different kinds of peripheral IP. Each comparator is capable of asserting interrupts to the NVIC or waking up the MCU from the Sleep or Deep Sleep mode through the EXTI wakeup event management unit.

## I/O Ports – GPIO

- Up to 29 GPIOs
- Port A, B, C are mapped to 16-line EXTI interrupts
- Almost all I/O pins have configurable output driving current

There are up to 29 General Purpose I/O pins, GPIO for the implementation of logic input/output functions. Each of the GPIO ports has a series of related control and configuration registers to maximize flexibility and to meet the requirements of a wide range of applications.

The GPIO ports are pin-shared with other alternative functions (AFs) to obtain maximum functional flexibility on the package pins. The GPIO pins can be used as alternative functional pins by configuring the corresponding registers regardless of the input or output pins. The external interrupts on the GPIO pins of the device have related control and configuration registers in the External Interrupt Control Unit, EXTI.

## Motor Control Timer – MCTM

- 16-bit up, down, up/down auto-reload counter
- Up to 4 independent channels
- 16-bit programmable prescaler that allows division of the prescaler clock source by any factor between 1 and 65536 to generate the counter clock frequency
- Input Capture function
- Compare Match Output
- PWM waveform generation with edge-aligned and center-aligned counting modes
- Single Pulse Mode Output
- Complementary outputs with programmable dead-time insertion
- Break input signals to assert the timer output signals in reset state or in a known fixed state

The Motor Control Timer, MCTM, consists of one 16-bit up/down-counter, four 16-bit Capture/Compare Registers (CCRs), one 16-bit Counter Reload Register (CRR), one 8-bit repetition counter and several control/status registers. It can be used for a variety of purposes which include input signal pulse width measurement, output waveform generation for signals such as compare match outputs, PWM outputs or complementary PWM outputs with dead-time insertion. The MCTM is capable of offering full functional support for motor control, hall sensor interfacing and break input.

## General-Purpose Timer – GPTM

- 16-bit up, down, up/down auto-reload counter
- Up to 4 independent channels for each timer
- 16-bit programmable prescaler that allows division of the prescaler clock source by any factor between 1 and 65536 to generate the counter clock frequency
- Input Capture function

- Compare Match Output
- PWM waveform generation with edge-aligned and center-aligned counting modes
- Single Pulse Mode Output
- Encoder interface controller with two inputs using quadrature decoder and Pulse/Direction Mode
- Master/Slave mode controller

The General-Purpose Timer, GPTM, consists of one 16-bit up/down-counter, four 16-bit Capture/Compare Registers (CCRs), one 16-bit Counter Reload Register (CRR) and several control/status registers. It can be used for a variety of purposes including general timer, input signal pulse width measurement, output waveform generation such as single pulse generation or PWM outputs. The GPTM also supports an encoder interface using a quadrature decoder with two inputs.

## Single Channel Timer – SCTM

- 16-bit auto-reload up-counter
- One channel for each timer
- 16-bit programmable prescaler that allows division of the prescaler clock source by any factor between 1 and 65536 to generate the counter clock frequency
- Input Capture function
- Compare Match Output
- PWM waveform generation with edge-aligned counting mode

The Single Channel Timer, SCTM, consists of one 16-bit up-counter, one 16-bit Capture / Compare Register (CCR), one 16-bit Counter-Reload Register (CRR) and several control/status registers. It can be used for a variety of purposes including general timer, input signal pulse width measurement or output waveform generation such as PWM outputs.

## Basic Function Timer – BFTM

- 32-bit compare match up-counter – no I/O control features
- One shot mode – stops counting when compare match occurs
- Repetitive mode – restarts counter when compare match occurs

The Basic Function Timer, BFTM, is a simple 32-bit up-counting counter designed to measure time intervals, generate one shot pulses or generate repetitive interrupts. The BFTM can operate in two modes which are repetitive and one shot modes. In the repetitive mode, the counter is restarted at each compare match event. The BFTM also supports a one shot mode which will force the counter to stop counting when a compare match event occurs.

## Watchdog Timer – WDT

- 12-bit down-counter with 3-bit prescaler
- Provides reset to the system
- Programmable watchdog timer window function
- Register write protection function

The Watchdog Timer is a hardware timing circuitry that can be used to detect a system lock-up due to software trapped in a deadlock. It includes a 12-bit count-down counter, a prescaler, a WDT delta value register, WDT operation control circuitry and a WDT protection mechanism. If the software does not reload the counter value before a Watchdog Timer underflow occurs, a reset will be generated when the counter underflows. In addition, a reset is also generated if the software reloads

the counter before it reaches a delta value. It means that the counter reload must occur when the Watchdog timer value has a value within a limited window using a specific method. The Watchdog Timer counter can be stopped when the processor is in the debug mode. The register write protection function can be enabled to prevent an unexpected change in the Watchdog timer configuration.

## Low Speed Timer – LSTM

- 24-bit up-counter with a programmable prescaler
- Alarm function
- Interrupt and wake-up control

The Low Speed Timer, LSTM, circuitry includes the APB interface, a 24-bit count-up counter, a control register, a prescaler, a compare register and a status register. The LSTM circuits are located in the  $V_{CORE}$  power domain. When the device enters the power-saving mode, the LSTM counter is used as a wakeup timer to let the system resume from the power saving mode.

## Inter-Integrated Circuit – I<sup>2</sup>C

- Supports both master and slave modes with a frequency of up to 1 MHz
- Provides an arbitration function and clock synchronization
- Supports 7-bit and 10-bit addressing modes and general call addressing
- Supports slave multi-addressing mode using address mask function

The I<sup>2</sup>C module is an internal circuit allowing communication with an external I<sup>2</sup>C interface which is an industry standard two-wire serial interface used for connection to external hardware. These two serial lines are known as a serial data line SDA, and a serial clock line SCL. The I<sup>2</sup>C module provides three data transfer rates: 100 kHz in the Standard mode; 400 kHz in the Fast mode; 1 MHz in the Fast plus mode. The SCL period generation registers are used to set different kinds of duty cycle implementation for the SCL pulse.

The SDA line which is connected directly to the I<sup>2</sup>C bus is a bidirectional data line between the master and slave devices and is used for data transmission and reception. The I<sup>2</sup>C module also has an arbitration detection and clock synchronization function to prevent situations where more than one master attempts to transmit data to the I<sup>2</sup>C bus at the same time.

## Serial Peripheral Interface – SPI

- Supports both master and slave modes
- Frequency of up to  $(f_{PCLK}/2)$  MHz for the master mode and  $(f_{PCLK}/3)$  MHz for the slave mode
- FIFO Depth: 8 levels
- Multi-master and multi-slave operation

The Serial Peripheral Interface, SPI, provides an SPI protocol data transmit and receive function in both master and slave modes. The SPI interface uses 4 pins, among which are serial data input and output lines MISO and MOSI, the clock line SCK, and the slave select line SEL. One SPI device acts as a master who controls the data flow using the SEL and SCK signals to indicate the start of the data communication and the data sampling rate. To receive the data bits, the streamlined data bits are latched on a specific clock edge and stored in the data register or in the RX FIFO. Data transmission is carried out in a similar way but with the reverse sequence. The mode fault detection provides a capability for multi-master applications.

## Universal Asynchronous Receiver Transmitter – UART

- Asynchronous serial communication operating baud-rate clock frequency up to ( $f_{PCLK}/16$ ) MHz
- Full duplex communication
- Fully programmable serial communication characteristics including:
  - Word length: 7, 8 or 9-bit character
  - Parity: Even, odd or no-parity bit generation and detection
  - Stop bit: 1 or 2 stop bits generation
  - Bit order: LSB-first or MSB-first transfer
- Error detection: Parity, overrun and frame error

The Universal Asynchronous Receiver Transceiver, UART, provides a flexible full duplex data exchange using asynchronous transfer. The UART is used to translate data between parallel and serial interfaces, and is commonly used for RS232 standard communication. The UART peripheral function supports Line Status Interrupt. The software can detect a UART error status by reading the UART Status & Interrupt Flag Register, URSIFR. The status includes the type and the condition of transfer operations as well as several error conditions resulting from Parity, Overrun, Framing and Break events.

## Universal Synchronous Asynchronous Receiver Transmitter – USART

- Supports both asynchronous and clocked synchronous serial communication modes
- Programmable baud rate clock frequency up to ( $f_{PCLK}/16$ ) MHz for asynchronous mode and ( $f_{PCLK}/8$ ) MHz for synchronous mode
- Full duplex communication
- Fully programmable serial communication characteristics including:
  - Word length: 7, 8 or 9-bit character
  - Parity: Even, odd or no-parity bit generation and detection
  - Stop bit: 1 or 2 stop bits generation
  - Bit order: LSB-first or MSB-first transfer
- Error detection: Parity, overrun and frame error
- Auto hardware flow control mode – RTS, CTS
- IrDA SIR encoder and decoder
- RS485 mode with output enable control
- FIFO Depth: 8-level for both receiver and transmitter

The Universal Synchronous Asynchronous Receiver Transceiver, USART, provides a flexible full duplex data exchange using synchronous or asynchronous transfer. The USART is used to translate data between parallel and serial interfaces, and is commonly used for RS232 standard communication. The USART peripheral function supports four types of interrupt including Line Status Interrupt, Transmitter FIFO Empty Interrupt, Receiver Threshold Level Reaching Interrupt and Time Out Interrupt. The USART module includes an 8-level transmitter FIFO, (TX\_FIFO) and an 8-level receiver FIFO (RX\_FIFO). The software can detect a USART error status by reading USART Status & Interrupt Flag Register, USRSIFR. The status includes the type and the condition of the transfer operations as well as several error conditions resulting from Parity, Overrun, Framing and Break events.

## Cyclic Redundancy Check – CRC

- Supports CRC16 polynomial: 0x8005,  
 $X^{16} + X^{15} + X^2 + 1$
- Supports CCITT CRC16 polynomial: 0x1021,  
 $X^{16} + X^{12} + X^5 + 1$
- Supports IEEE-802.3 CRC32 polynomial: 0x04C11DB7,  
 $X^{32} + X^{26} + X^{23} + X^{22} + X^{16} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^5 + X^4 + X^2 + X + 1$
- Supports 1's complement, byte reverse & bit reverse operation on data and checksum
- Supports byte, half-word & word data size
- Programmable CRC initial seed value
- CRC computation executed in 1 AHB clock cycle for 8-bit data and 4 AHB clock cycles for 32-bit data
- Supports PDMA to complete a CRC computation of a block of memory

The CRC calculation unit is an error detection technique test algorithm and is used to verify data transmission or storage data correctness. A CRC calculation takes a data stream or a block of data as its input and generates a 16-bit or 32-bit output remainder. Ordinarily, a data stream is suffixed by a CRC code and used as a checksum when being sent or stored. Therefore, the received or restored data stream is calculated by the same generator polynomial as described above. If the new CRC code result does not match the one calculated earlier, that means the data stream contains a data error.

## Peripheral Direct Memory Access – PDMA

- 6 channels with trigger source grouping
- 8-bit, 16-bit and 32-bit width data transfer
- Supports linear address, circular address and fixed address modes
- 4-level programmable channel priority
- Auto reload mode
- Supports trigger sources:  
ADC, SPI, USART, UART, I<sup>2</sup>C, MCTM, GPTM, SCTM and software request

The Peripheral Direct Memory Access circuitry, PDMA, moves data between the peripherals and the system memory on the AHB bus. Each PDMA channel has a source address, destination address, block length and transfer count. The PDMA can exclude the CPU intervention and avoid interrupt service routine execution. It improves system performance as the software does not need to connect each data movement operation.

## Hardware Divider – DIV

- Signed/unsigned 32-bit divider
- Calculate in 8 clock cycles, load in 1 clock cycle
- Division by zero error Flag

The divider is the truncated division and requires a software triggered start signal by controlling the “START” bit in the control register. The divider calculation complete flag will be set to 1 after 8 clock cycles, however, if the divisor register data is zero during the calculation, the division by zero error flag will be set to 1.

## Debug Support

- Serial Wire Debug Port – SW-DP
- 4 comparators for hardware breakpoint or code / literal patch
- 2 comparators for hardware watch points

## Package and Operation Temperature

- 32-pin QFN and 48-pin LQFP-EP packages
- Operation temperature range: -40 °C to 105 °C

# 3 Overview

## Device Information

**Table 1. Features and Peripheral List**

Peripherals		HT32F65432A
Main Flash (KB)		31
Option Bytes Flash (KB)		1
SRAM (KB)		4
Timers	MCTM	1
	GPTM	1
	SCTM	4
	BFTM	2
	WDT	1
	LSTM	1
Communication	USART	1
	UART	1
	SPI	1
	I <sup>2</sup> C	1
PDMA		6 channels
Hardware Divider		1
CRC-16/32		1
EXTI		16
12-bit ADC		1
Number of channels		12 external channels
Comparator		2
Operational Amplifier		1
Gate-Driver		3-channel 36 V Half-bridge P/N Gate-Driver
GPIO		Up to 29
CPU frequency		Up to 60 MHz
Power supply (V <sub>CC</sub> )		6 V ~ 32 V
Operating voltage (V <sub>DD</sub> )		2.5 V ~ 5.5 V
5 V LDO output driving current		50 mA
Operating temperature		-40 °C ~ 105 °C
Package		32-pin QFN and 48-pin LQFP-EP

## Block Diagram

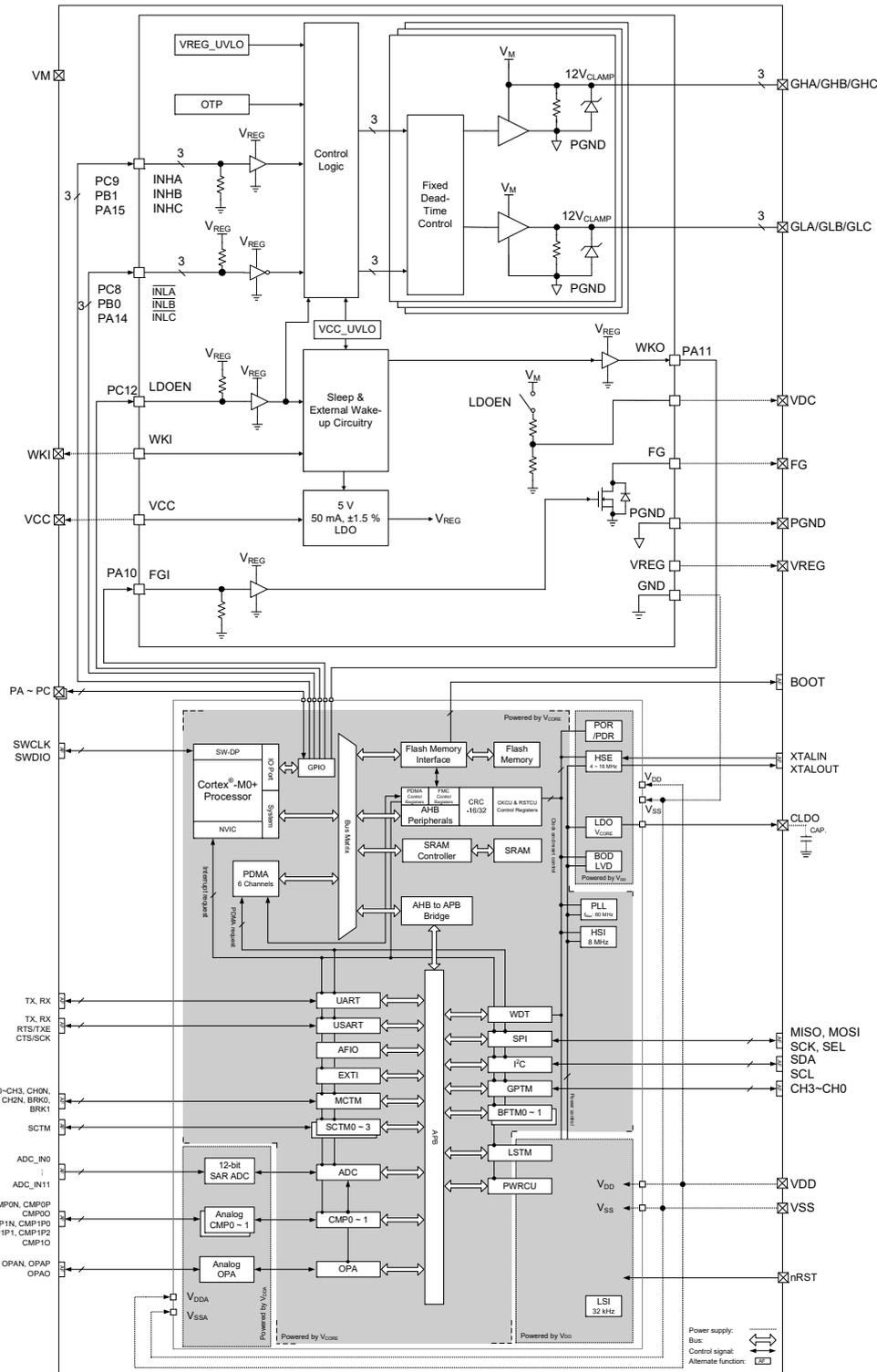


Figure 1. Block Diagram

## Memory Map

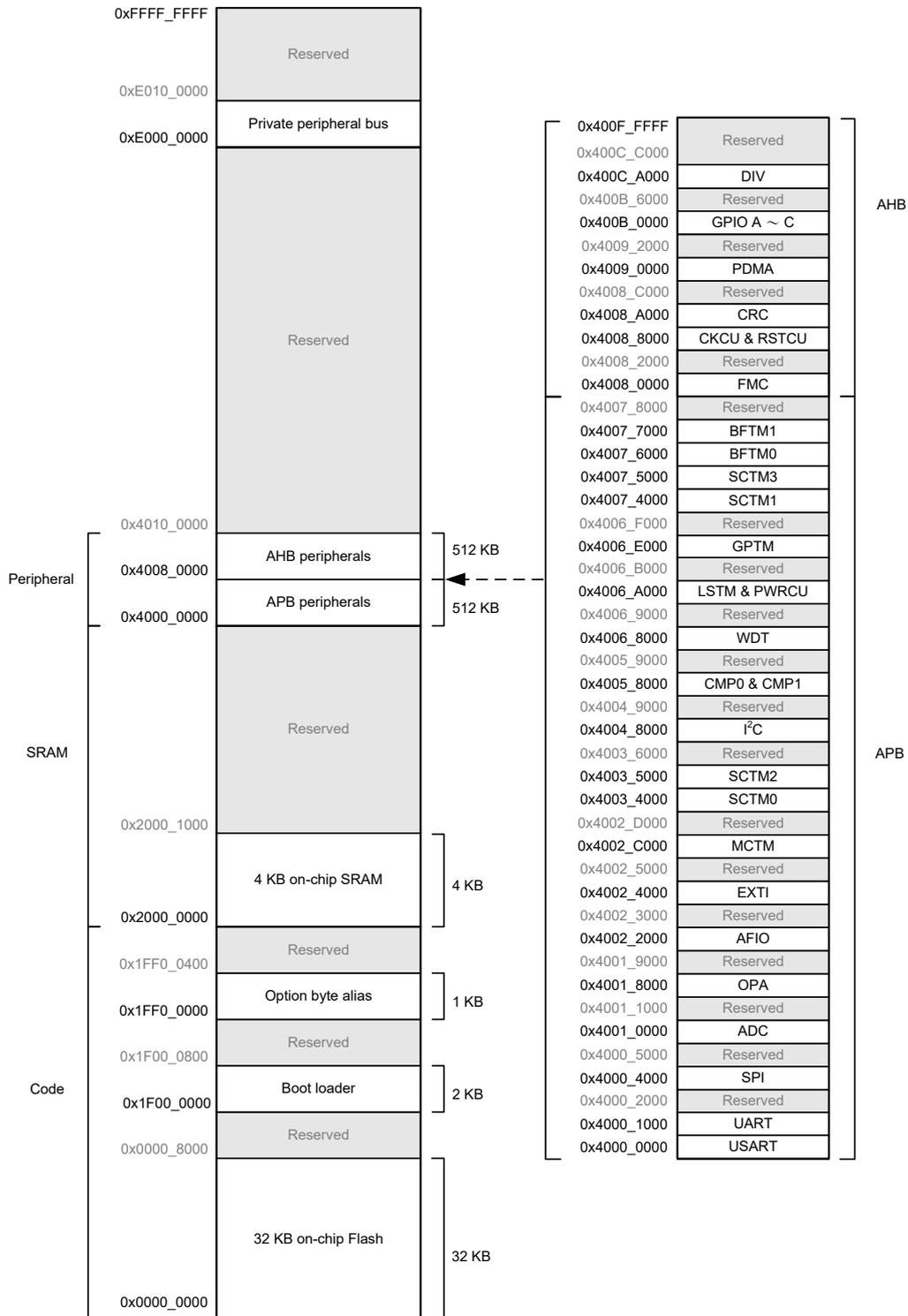


Figure 2. Memory Map

**Table 2. Register Map**

Start Address	End Address	Peripheral	Bus
0x4000_0000	0x4000_0FFF	USART	APB
0x4000_1000	0x4000_1FFF	UART	
0x4000_2000	0x4000_3FFF	Reserved	
0x4000_4000	0x4000_4FFF	SPI	
0x4000_5000	0x4000_FFFF	Reserved	
0x4001_0000	0x4001_0FFF	ADC	
0x4001_1000	0x4001_7FFF	Reserved	
0x4001_8000	0x4001_8FFF	OPA	
0x4001_9000	0x4002_1FFF	Reserved	
0x4002_2000	0x4002_2FFF	AFIO	
0x4002_3000	0x4002_3FFF	Reserved	
0x4002_4000	0x4002_4FFF	EXTI	
0x4002_5000	0x4002_BFFF	Reserved	
0x4002_C000	0x4002_CFFF	MCTM	
0x4002_D000	0x4003_3FFF	Reserved	
0x4003_4000	0x4003_4FFF	SCTM0	
0x4003_5000	0x4003_5FFF	SCTM2	
0x4003_6000	0x4004_7FFF	Reserved	
0x4004_8000	0x4004_8FFF	I <sup>2</sup> C	
0x4004_9000	0x4005_7FFF	Reserved	
0x4005_8000	0x4005_8FFF	CMP0 & CMP1	
0x4005_9000	0x4006_7FFF	Reserved	
0x4006_8000	0x4006_8FFF	WDT	
0x4006_9000	0x4006_9FFF	Reserved	
0x4006_A000	0x4006_AFFF	LSTM & PWRCU	
0x4006_B000	0x4006_DFFF	Reserved	
0x4006_E000	0x4006_EFFF	GPTM	
0x4006_F000	0x4007_3FFF	Reserved	
0x4007_4000	0x4007_4FFF	SCTM1	
0x4007_5000	0x4007_5FFF	SCTM3	
0x4007_6000	0x4007_6FFF	BFTM0	
0x4007_7000	0x4007_7FFF	BFTM1	
0x4007_8000	0x4007_FFFF	Reserved	

Start Address	End Address	Peripheral	Bus
0x4008_0000	0x4008_1FFF	FMC	AHB
0x4008_2000	0x4008_7FFF	Reserved	
0x4008_8000	0x4008_9FFF	CKCU & RSTCU	
0x4008_A000	0x4008_BFFF	CRC	
0x4008_C000	0x4008_FFFF	Reserved	
0x4009_0000	0x4009_1FFF	PDMA	
0x4009_2000	0x400A_FFFF	Reserved	
0x400B_0000	0x400B_1FFF	GPIO A	
0x400B_2000	0x400B_3FFF	GPIO B	
0x400B_4000	0x400B_5FFF	GPIO C	
0x400B_6000	0x400C_9FFF	Reserved	
0x400C_A000	0x400C_BFFF	DIV	
0x400C_C000	0x400F_FFFF	Reserved	



# 4 Gate-Driver

The device includes a 3-channel gate-driver, which can be used for external high-side P-type MOSFETs and low-side N-type MOSFETs driving. It includes a 5 V LDO, 3-channel high-side and low-side gate-driver circuits. The device also has three protection functions, which are  $V_{CC}$  Power Supply Input Under Voltage Lock-Out, 5 V LDO Output Under Voltage Lock-Out and Over Temperature Protection, to avoid abnormal output situations.

The input signals of  $INHx$ ,  $\overline{INLx}$  and LDOEN are input to the control logic which will determine the high-side and low-side gate-driver outputs. The  $INHx$  has an internal pull-down resistor and the  $\overline{INLx}$  has an internal pull-up resistor. Additionally, there is a fixed dead time insertion when switching between the high-side and low-side gate driving to avoid short-circuit between  $V_M$  and ground.

The gate-driver output voltage will vary with the power supply. The gate-driver provides 0.35 A peak source current and 0.5 A peak sink current when  $V_{CC}$  is 24 V. Either high-side and low-side gate has an internal hold-off resistor in order to avoid error conduction of external power MOSFET due to interference when the power is off.

The gate-driver also provides a high voltage open-drain output FG signal, providing information about rotation speed of the motor.

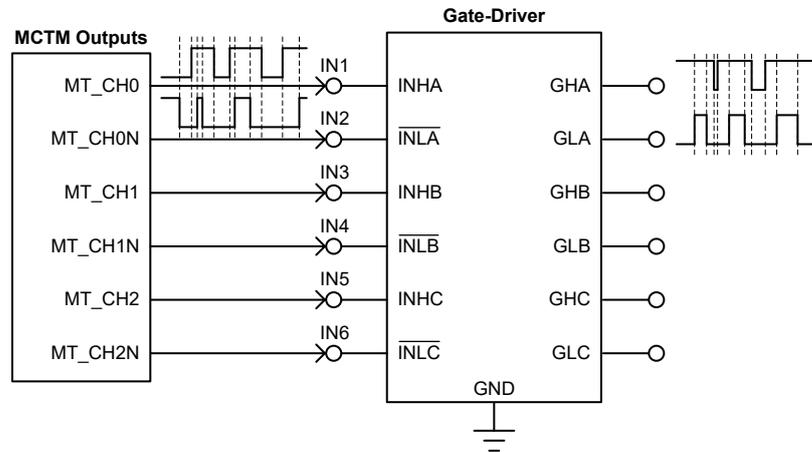
In addition, if the gate-driver enters the SLEEP mode, all functions will be turned off to greatly reduce the sleep current.

## Voltage Regulator

The integrated 5 V LDO can supply power for both internal and external circuits, with a output current over 50 mA. The LDO will act as a fully turned on switch when the power supply  $V_{CC}$  is less than 5 V, in which condition its output voltage is almost equal to the power supply if there is no load.

## Gate-Driver Control Logic

As a gate-driver for driving high-side P-type MOSFETs and low-side N-type MOSFETs, the control signals are input from LDOEN,  $INHx$ ,  $\overline{INLx}$ . Usually a 6-wire input control method is used, where the dead time width is determined by the control signals but has a minimum value equal to the fixed dead time designed in the device.



**Figure 4. 6-Wire Control**

Both high-side and low-side gate-driver outputs are controlled by the LDOEN, INHx and  $\overline{\text{INLx}}$  input signals. For example, the on / off true table of the external power MOSFETs is shown as follows.

**Table 3. Gate-Driver Operation Truth Table**

LDOEN	INHx	$\overline{\text{INLx}}$	VM-to-GHx	GLx-to-VSS	V <sub>REG</sub>	External High-Side Power MOSFET	External Low-Side Power MOSFET
0	X	X	H	L	0 V	OFF	OFF
1	0	0	H	H	V <sub>REG</sub>	OFF	ON
1	0	1	H	L	V <sub>REG</sub>	OFF	OFF
1	1	0	H	L	V <sub>REG</sub>	OFF	OFF
1	1	1	L	L	V <sub>REG</sub>	ON	OFF

X: No care; L: Low; H: High

## Protection Function Operation

When the device operates in an abnormal situation, such as a V<sub>CC</sub> Power Supply Input Under Voltage Lock-Out, 5 V LDO Output Under Voltage Lock-Out or Over Temperature Protection condition has occurred, it will activate the corresponding protection mechanism to turn off the affected power MOSFET. The protection mechanisms are summarized below.

**Table 4. Protection Function Conditions**

Protection	Protection Entry Condition	Protection Reaction			Release Condition
		V <sub>REG</sub>	V <sub>CC</sub> -to-GHx	GLx-to-VSS	
V <sub>CC</sub> _UVLO	V <sub>CC</sub> < V <sub>CC_UVLO-</sub>	0 V	H	L	V <sub>CC</sub> ≥ V <sub>CC_UVLO+</sub>
V <sub>REG</sub> _UVLO	V <sub>REG</sub> < V <sub>REG_UVLO-</sub>	—	H	L	V <sub>REG</sub> ≥ V <sub>REG_UVLO+</sub>
OTP	T <sub>J</sub> > T <sub>SHD</sub>	—	H	L	T <sub>J</sub> ≤ T <sub>REC</sub>

L: Low; H: High

Note: The LDO will not be turned off after the protection is triggered.

## V<sub>CC</sub> Power Supply Input Under Voltage Lock-Out – V<sub>CC\_UVLO</sub>

This integrated protection function is to avoid unstable gate-driver output when the power supply voltage falls to a certain low level. During V<sub>CC</sub> power-on period, both high-side and low-side power MOSFETs are turned off and the LDO is in the sleep state and the LDO output is 0 V before the power supply voltage reaching the threshold V<sub>CC\_UVLO+</sub>. When the power supply voltage is greater than V<sub>CC\_UVLO+</sub>, the gate-driver outputs are determined by the input signals, the LDO is woken-up and the LDO output is determined by the input signals. If the power supply voltage falls below the under voltage lock-out threshold V<sub>CC\_UVLO-</sub>, both high-side and low-side power MOSFETs will remain off and the LDO will enter sleep state and output 0 V.

## 5 V LDO Output Under Voltage Lock-Out – V<sub>REG\_UVLO</sub>

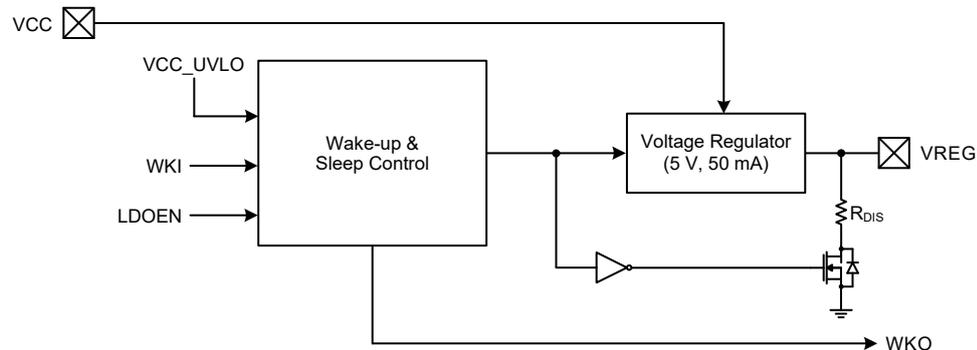
When the internal 5 V LDO output voltage, V<sub>REG</sub>, is too low, the integrated 5 V LDO output under voltage lock-out function will be activated to avoid unstable signals input from the external controller. After V<sub>REG</sub> exceeds the threshold V<sub>REG\_UVLO+</sub>, the gate-driver output is determined by the input signals. If V<sub>REG</sub> is less than the under voltage lock-out threshold V<sub>REG\_UVLO-</sub>, both high-side and low-side power MOSFETs will remain off.

## Over Temperature Protection – OTP

If the internal junction temperature of the gate-driver exceeds the limit threshold T<sub>SHD</sub>, the high-side and low-side power MOSFETs will be turned off until the junction temperature drops below the recovery temperature level, T<sub>REC</sub>, at which the gate-driver output is determined by the input signals.

## Ultra-low Power Consumption

When the control signal LDOEN is cleared to zero, the LDO will be turned off, that is, the system power in the V<sub>REG</sub> domain will be turned off. In the SLEEP mode, the current consumption is less than 1 μA, the gate-driver will wait for an external wake-up signal by monitoring the WKI. Once a valid wake-up signal on the WKI is triggered, if the voltage level is boosted by more than 5 V within 1 ms, the LDO output will be restored and the system will return to normal operation.



**Figure 5. Enter the SLEEP Mode and Wake-up Function Block Diagram**

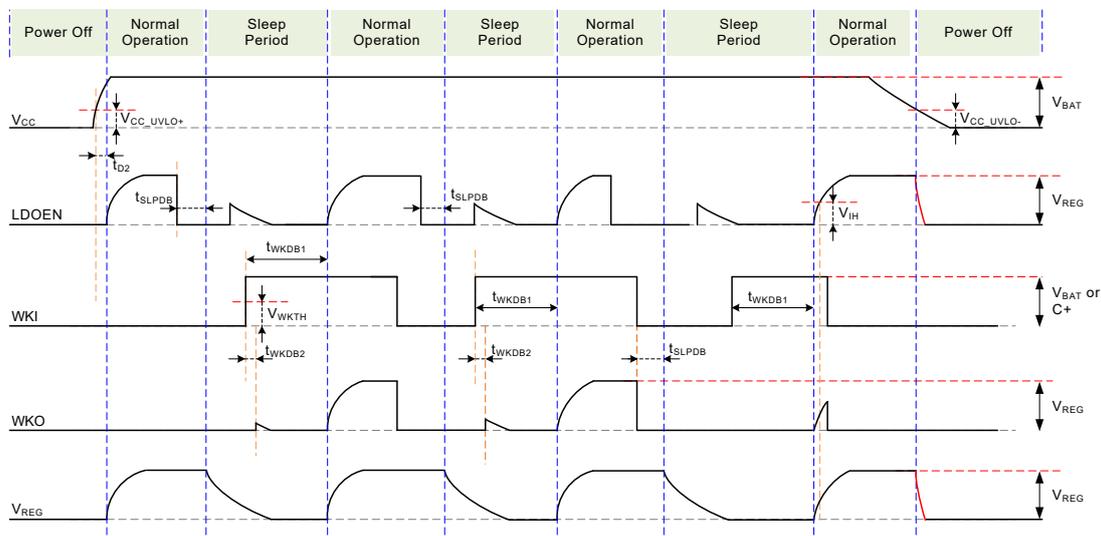


Figure 6. Enter the SLEEP Mode and Wake-up Function Timing

## FG High Voltage Motor Speed Signal

The gate-driver provides a high-voltage open-drain mechanism, which can convert the low-voltage signal input from the FGI to a high-voltage signal and output it to the FG. This mechanism provides an interface to monitor the motor speed signal. When FGI input is high level, the FG output will be 0 V, and when FGI input is low, the FG output is in high impedance state.

Table 5. FG Output Truth Table

LDOEN	FGI	FG
LDOEN = '0'	X	Z
LDOEN = '1'	'1'	L
LDOEN = '1'	'0'	Z

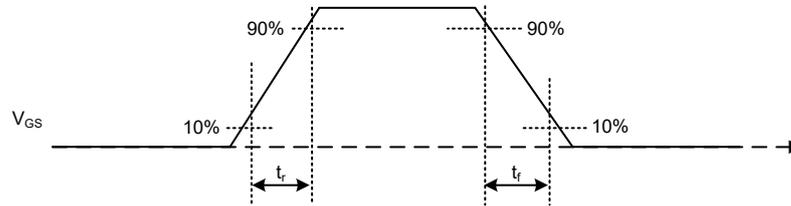
X: No care; L: Low; Z: High impedance

## Component Selections

### Gate Resistor Circuit

The main function of the gate resistors,  $R_{G1}$ ,  $R_{G2}$ ,  $R_{G3}$  and  $R_{G4}$ , is to reduce the vibration of U, V, W output voltages and reduce the EMI noise generation. Adjusting  $R_{G1}$  and  $R_{G3}$  controls the on time of the high-side and low-side switches, adjusting  $R_{G2}$  and  $R_{G4}$  controls the off time of the high-side and low-side switches. The gate resistors are optional and can be used according to the requirements.

It is recommended to select the gate resistance value according to the desired gate voltage rising time ( $t_r$ ) or falling time ( $t_f$ ), which are shown in the figure below.  $R_{G1}$ ,  $R_{G2}$ ,  $R_{G3}$  and  $R_{G4}$ , if used, are recommended to have a typical value of  $10 \Omega \sim 200 \Omega$ . It is recommended to use a 1N4148 switch diode for both  $D_{G1}$  and  $D_{G2}$ .



**Figure 7. Gate Voltage ( $V_{GS}$ ) Rising Time ( $t_r$ ) and Falling Time ( $t_f$ )**

### Current Sensing Resistors

The current sensing resistors,  $R_S$ , turns the current flowing through it into a voltage for the controller to detect. The current sensing resistors are optional and can be used according to the requirements. It is recommended that the current sensing resistors be used when the cross voltage is less than 0.5 V.

Pay attention to the power that the current sensing resistors can withstand,  $P_{RS}$ , which is calculated by  $P_{RS} = R_S \times I_{RMS}^2$ , where  $R_S$  is the resistance value,  $I_{RMS}$  is the effective value of the current flowing through the resistor. The package of the current sensing resistor should be selected based on the power calculated above.

### FG Pull-Up Resistors

The suggested value for the pull-up resistor,  $R_2$ , connected between the FG pin and the  $V_{BAT}$  is 10 k $\Omega$ .

### Gate-Driver Supply Capacitor

The power supply regulator capacitors,  $C_1$  and  $C_5$  can reduce input voltage fluctuation.  $C_1$  is recommended to use at least a 4.7  $\mu\text{F}$  capacitor and  $C_5$  is recommended to use at least a 10  $\mu\text{F}$  capacitor.

### Power Supply Bypass Capacitor

When the board power supply is mains, the power supply bypass capacitor,  $C_4$ , can filter out the high-frequency noise input from the power supply. It is recommended to use a 0.1  $\mu\text{F}$  capacitor. This capacitor is optional and can be used according to the requirements.

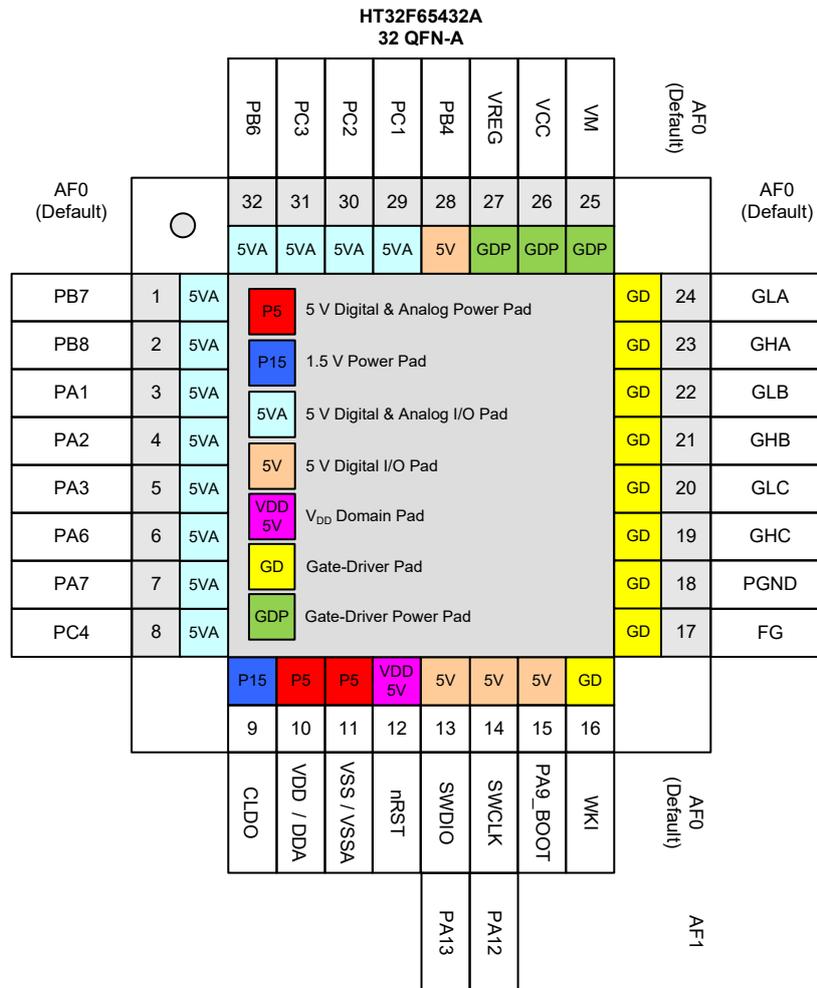
### Motor Supply Capacitor

The motor power supply capacitor,  $C_3$ , can absorb the current that is fed back to the  $V_M$  power supply when the motor is running, and can also provide a transient power for motor to compensate for the power response speed or the influence of external wire length.

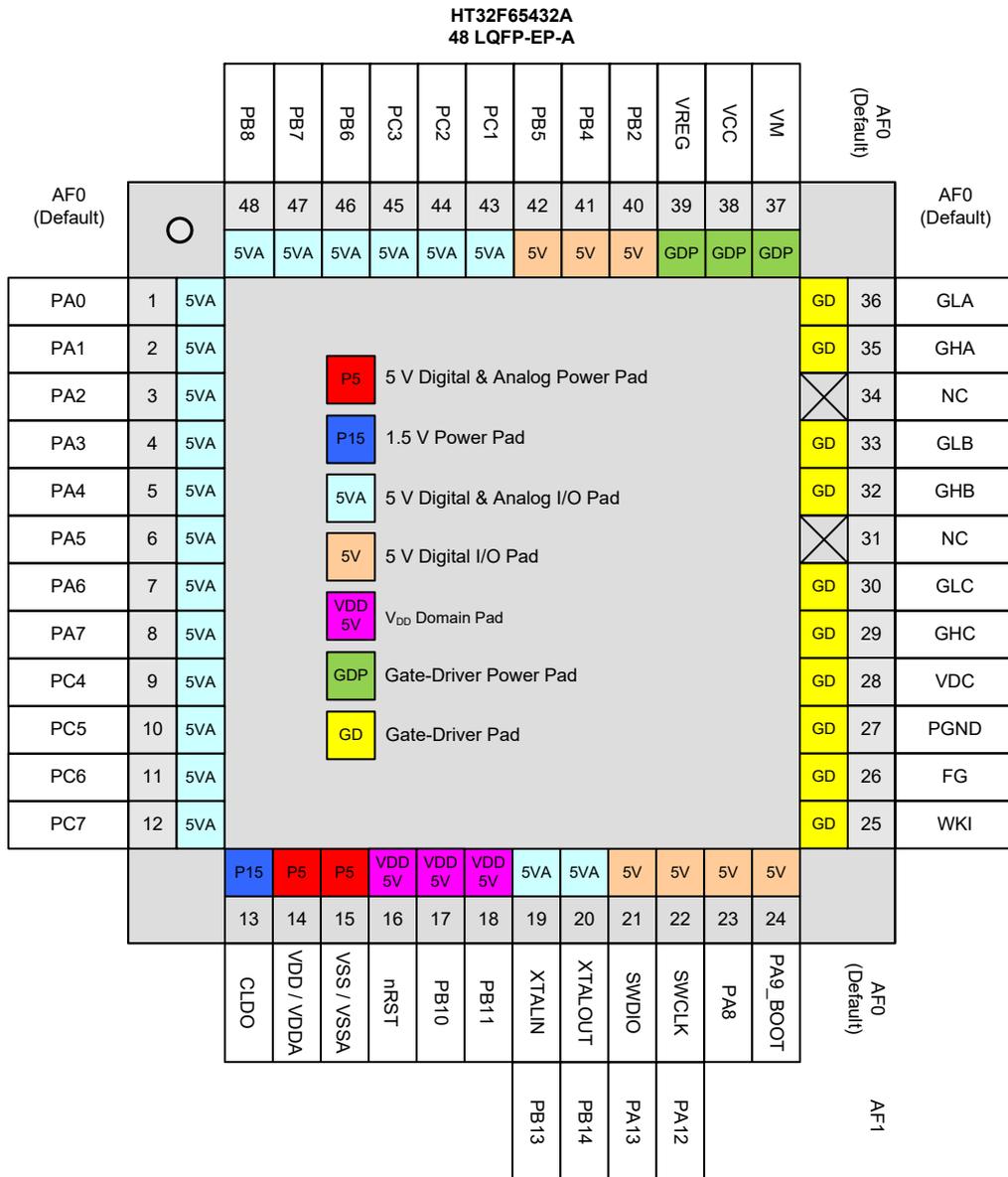
### LDO Output Capacitor

The LDO output regulator capacitor,  $C_2$ , can reduce the voltage ripple of the LDO output. It is recommended to use at least a 2.2  $\mu\text{F}$  capacitor.

# 5 Pin Assignment



**Figure 8. 32-pin QFN Pin Assignment**



5 Pin Assignment

**Figure 9. 48-pin LQFP-EP Pin Assignment**

**Table 6. Pin Assignment**

Package		Alternate Function Mapping															
48 LQFP-EP	32 QFN	AF0 System Default	AF1 GPIO	AF2 ADC0	AF3 N/A	AF4 GPTM /MCTM	AF5 SPI	AF6 USART /UART	AF7 I <sup>2</sup> C	AF8 CMP/ OPA	AF9 SCTM	AF10 N/A	AF11 N/A	AF12 N/A	AF13 MCTM	AF14 MCTM	AF15 System Other
1		PA0		ADC_IN5				USR_RTS			SCTM0						
2	3	PA1		ADC_IN6				USR_RX	I2C_SCL		SCTM1						
3	4	PA2		ADC_IN7		MT_BRK0	SPI_SCK	USR_CTS		CMP00							
4	5	PA3		ADC_IN8		MT_BRK1	SPI_MISO	USR_TX	I2C_SDA	CMP0N							
5		PA4					SPI_SEL	UR_TX	I2C_SCL	CMP0P	SCTM2						
6		PA5					SPI_MOSI	UR_RX	I2C_SDA		SCTM3						
7	6	PA6								OPAP							
8	7	PA7				GT_CH0				OPAN	SCTM2						
9	8	PC4				GT_CH1	SPI_MOSI	USR_TX		OPAO							
10		PC5		ADC_IN9		GT_CH2	SPI_MISO	USR_RX			SCTM0						
11		PC6		ADC_IN10		GT_CH3	SPI_SEL	USR_RTS									
12		PC7		ADC_IN11			SPI_SCK	USR_CTS			SCTM3						
13	9	CLDO															
14	10	VDD/ VDDA															
15	11	VSS/ VSSA															
16	12	nRST															
17		PB10						UR_RX	I2C_SCL								
18		PB11						UR_TX	I2C_SDA								
19		XTALIN	PB13			MT_CH3		USR_RTS									
20		XTALOUT	PB14			MT_BRK0	SPI_SCK	USR_CTS			SCTM1						
21	13	SWDIO	PA13					UR_TX	I2C_SDA								
22	14	SWCLK	PA12					UR_RX	I2C_SCL								
23		PA8				GT_CH0	SPI_SCK	USR_TX	I2C_SCL		SCTM0						
24	15	PA9_BOOT				GT_CH3	SPI_SEL	USR_RX	I2C_SDA								CKOUT
25	16	WKI															
26	17	FG															
27	18	PGND															
28		VDC															
29	19	GHC															
30	20	GLC															
32	21	GHB															
33	22	GLB															
35	23	GHA															
36	24	GLA															

Package		Alternate Function Mapping															
48 LQFP-EP	32 QFN	AF0 System Default	AF1 GPIO	AF2 ADC0	AF3 N/A	AF4 GPTM /MCTM	AF5 SPI	AF6 USART /UART	AF7 I <sup>2</sup> C	AF8 CMP/ OPA	AF9 SCTM	AF10 N/A	AF11 N/A	AF12 N/A	AF13 MCTM	AF14 MCTM	AF15 System Other
37	25	VM															
38	26	VCC															
39	27	VREG															
40		PB2				MT_CH0N					SCTM0				MT_CH0	MT_CH1	CKIN
41	28	PB4				MT_CH2	SPI_SEL	UR_TX			SCTM3				MT_CH2N		
42		PB5					SPI_SCK										
43	29	PC1				MT_BRK0	SPI_MOSI	UR_RX		CMP10	SCTM0						
44	30	PC2		ADC_IN0		MT_CH3	SPI_MISO				SCTM1						
45	31	PC3		ADC_IN1		GT_CH3				CMP1N							
46	32	PB6		ADC_IN2		GT_CH2			I2C_SCL	CMP1P2	SCTM2						
47	1	PB7		ADC_IN3		GT_CH1			I2C_SDA	CMP1P1							
48	2	PB8		ADC_IN4		GT_CH0		UR_TX		CMP1P0	SCTM3						
31, 36		NC															

**Table 7. Pin Description**

Pin Number		Pin Name	Type <sup>(1)</sup>	I/O Structure <sup>(2)</sup>	Output Driving	Description
48 LQFP-EP	32 QFN					Default Function (AF0)
1		PA0	AI/O	5V	4/8/12/16 mA	PA0
2	3	PA1	AI/O	5V	4/8/12/16 mA	PA1
3	4	PA2	AI/O	5V	4/8/12/16 mA	PA2
4	5	PA3	AI/O	5V	4/8/12/16 mA	PA3
5		PA4	AI/O	5V	4/8/12/16 mA	PA4, this pin provides a UART_TX function in the Boot loader mode
6		PA5	AI/O	5V	4/8/12/16 mA	PA5, this pin provides a UART_RX function in the Boot loader mode
7	6	PA6	AI/O	5V	4/8/12/16 mA	PA6
8	7	PA7	AI/O	5V	4/8/12/16 mA	PA7
9	8	PC4	AI/O	5V	4/8/12/16 mA	PC4
10		PC5	AI/O	5V	4/8/12/16 mA	PC5
11		PC6	AI/O	5V	4/8/12/16 mA	PC6
12		PC7	AI/O	5V	4/8/12/16 mA	PC7
13	9	CLDO	P	—	—	Core power LDO V <sub>CORE</sub> output It is recommended to connect a 2.2 μF capacitor as close as possible between this pin and VSS
14	10	VDD/ VDDA	P	—	—	Digital and analog voltage input
15	11	VSS/ VSSA <sup>(6)</sup>	P	—	—	Ground reference
16	12	nRST <sup>(3)</sup>	I	5V_PU	—	External reset pin
17		PB10 <sup>(3)</sup>	AI/O (V <sub>DD</sub> )	5V	4/8/12/16 mA	PB10
18		PB11 <sup>(3)</sup>	AI/O (V <sub>DD</sub> )	5V	4/8/12/16 mA	PB11
19		PB13	AI/O	5V	4/8/12/16 mA	XTALIN
20		PB14	AI/O	5V	4/8/12/16 mA	XTALOUT
23		PA8	I/O	5V	4/8/12/16 mA	PA8
24	15	PA9	I/O	5V_PU	4/8/12/16 mA	PA9_BOOT
22	14	PA12	I/O	5V_PU	4/8/12/16 mA	SWCLK
21	13	PA13	I/O	5V_PU	4/8/12/16 mA	SWDIO
25	16	WKI	I	—	—	External wake-up input. Keep floating when no use
26	17	FG	O	—	—	HV level shifter open-drain output
27	18	PGND	G	—	—	Gate-driver ground terminal
28		VDC	O	—	—	Motor power supply voltage divider output
29	19	GHC	O	—	—	High-side P-type MOSFET gate drive phase C
30	20	GLC	O	—	—	Low-side N-type MOSFET gate drive phase C
32	21	GHB	O	—	—	High-side P-type MOSFET gate drive phase B
33	22	GLB	O	—	—	Low-side N-type MOSFET gate drive phase B
35	23	GHA	O	—	—	High-side P-type MOSFET gate drive phase A
36	24	GLA	O	—	—	Low-side N-type MOSFET gate drive phase A
37	25	VM	P	—	—	Motor supply and gate driver supply input
38	26	VCC	P	—	—	VCC power supply input
39	27	VREG	O	—	—	Supplied from VCC. Regulated 5 V output
40		PB2	I/O	5V	4/8/12/16 mA	PB2
41	28	PB4	I/O	5V	4/8/12/16 mA	PB4

Pin Number		Pin Name	Type <sup>(1)</sup>	I/O Structure <sup>(2)</sup>	Output Driving	Description
48 LQFP-EP	32 QFN					Default Function (AF0)
42		PB5	I/O	5V	4/8/12/16 mA	PB5
43	29	PC1	AI/O	5V	4/8/12/16 mA	PC1
44	30	PC2	AI/O	5V	4/8/12/16 mA	PC2
45	31	PC3	AI/O	5V	4/8/12/16 mA	PC3
46	32	PB6	AI/O	5V	4/8/12/16 mA	PB6
47	1	PB7	AI/O	5V	4/8/12/16 mA	PB7
48	2	PB8	AI/O	5V	4/8/12/16 mA	PB8

Note: 1. I = Input, O = Output, A = Analog Port, P = Power Supply,  $V_{DD} = V_{DD}$  Power.

2. 5V = 5 V operation I/O type, PU = Pull-up.

3. These pins are located at the  $V_{DD}$  power domain.

4. The EP which means the thermally enhanced Exposed Pad on the packages must be connected to ground.

5. In the Boot loader mode, the UART interface is available for communication.

6. The VSS/VSSA is internally connected to the gate-driver GND line.

## Internal Connection Signals

The MCU generated signals such as the MCTM channel outputs have been internally connected to the gate-driver inputs for control purpose. The connections are listed in the following table and the related control registers should be configured correctly using application program.

**Table 8. Internal Connection Signal Lines**

Package		MCU Signal Name	Connection Gate-Driver Signal Name	Description
48 LQFP-EP	32 QFN			
•	•	PC9 / MT_CH0 (MCTM)	INHA	Control input for high-side gate drive phase A. High active. The MCU AFIO setting should be AF4 to select the MCTM pin function.
•	•	PC8 / MT_CH0N (MCTM)	/INLA	Control input for low-side gate drive phase A. Low active. The MCU AFIO setting should be AF4 to select the MCTM pin function.
•	•	PB1 / MT_CH1 (MCTM)	INHB	Control input for high-side gate drive phase B. High active. The MCU AFIO setting should be AF4 to select the MCTM pin function.
•	•	PB0 / MT_CH1N (MCTM)	/INLB	Control input for low-side gate drive phase B. Low active. The MCU AFIO setting should be AF4 to select the MCTM pin function.
•	•	PA15 / MT_CH2 (MCTM)	INHC	Control input for high-side gate drive phase C. High active. The MCU AFIO setting should be AF4 to select the MCTM pin function.
•	•	PA14 / MT_CH2N (MCTM)	/INLC	Control input for low-side gate drive phase C. Low active. The MCU AFIO setting should be AF4 to select the MCTM pin function.
•	•	PC12	LDOEN	LDO Enable line. High active. The MCU AFIO setting should be AF0 to select the General Purpose Input/Output pin function.
•	•	PA11	WKO	External wake-up output. An external high voltage wake-up signal input on the WKI pin will be converted into a low voltage, VREG, which is output by the WKO line and can be used as an interrupt signal for the MCU. Keep floating when no use. The MCU AFIO setting should be AF0 to select the General Purpose Input/Output pin function.
•	•	PA10	FGI	Control input of high voltage level shifter to FG. The MCU AFIO setting should be AF0 to select the General Purpose Input/Output pin function (GPIO).
	•	PC7 / ADC_IN11 (ADC)	VDC	Motor power supply voltage divider output. The MCU AFIO setting should be AF2 to select the ADC pin function. (For the 32QFN package only)

# 6 Application Circuits

## Typical Application Circuit – 1-Shunt Current Sensing

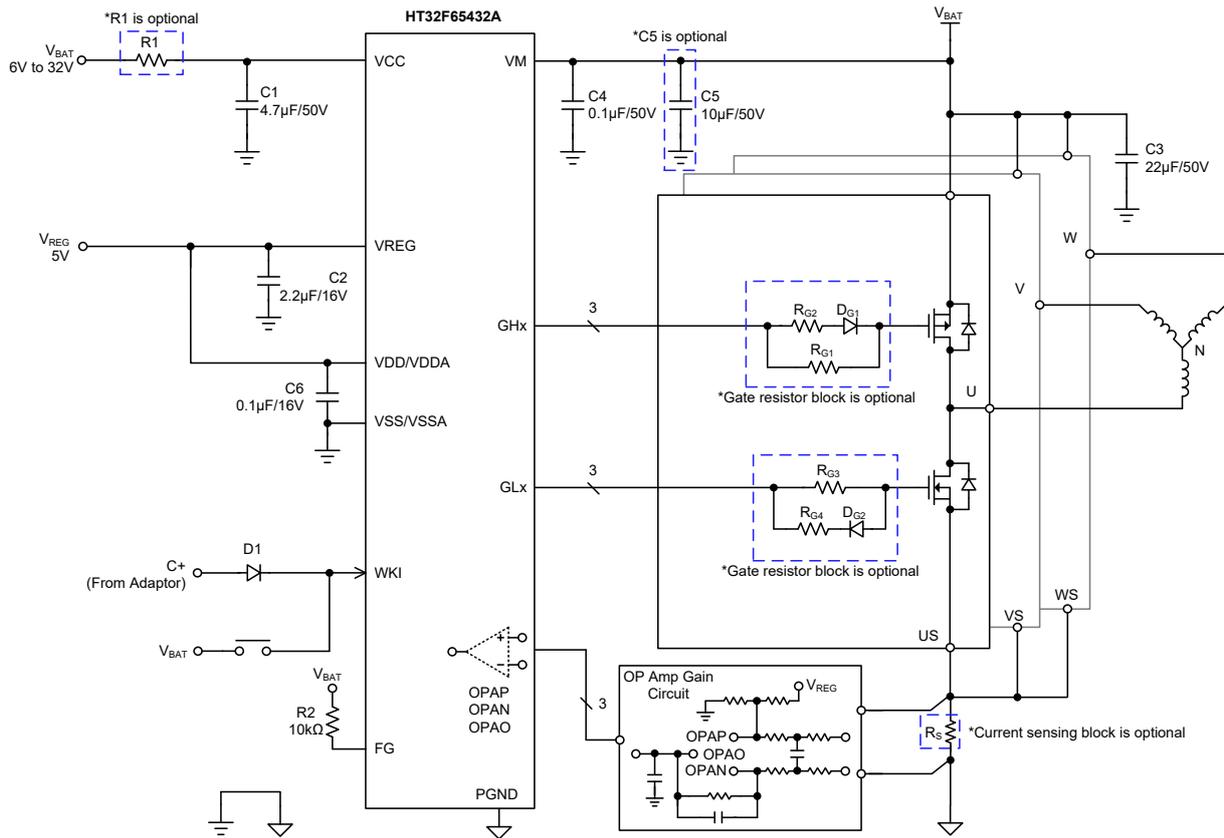


Figure 10. Typical Application Circuit – 1 Shunt Current Sensing

6 Application Circuits

# 7 Electrical Characteristics

## Absolute Maximum Ratings

The following table shows the absolute maximum ratings of the device. These are stress ratings only. Stresses beyond absolute maximum ratings may cause permanent damage to the device. Note that the device is not guaranteed to operate properly at the maximum ratings. Exposure to the absolute maximum rating conditions for extended periods may affect device reliability.

**Table 9. Absolute Maximum Ratings**

Parameter	Value	Unit
VCC, VM, WKI, FG	-0.3 to 36	V
VM-to-GHx	-0.3 to 36	V
GLx-to-PGND	-0.3 to 36	V
VREG, INHx, INLx, WKO, FGI, LDOEN	-0.3 to 7	V
PGND	-0.7 to 0.7	V
Operating Ambient Temperature Range	-40 to 105	°C
Maximum Junction Temperature	160	°C
Storage Temperature Range	-60 to 150	°C
Lead Temperature (Soldering 10s)	260	°C
Electrostatic Discharge Voltage	Human Body Model	±2000
	48LQFP-EP	50
Junction-to-Ambient Thermal Resistance, $\theta_{JA}$	48LQFP-EP	50
	32QFN	47

Note: For the GHx, GLx, INHx and INLx, where "x" stands for A, B or C.

## Recommended DC Operating Conditions

**Table 10. Recommended DC Operating Conditions**

$T_A = 25\text{ }^\circ\text{C}$ , unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$V_{CC}$	Power Supply Voltage	—	6	—	32	V
$V_{DD}$	Operating Voltage	—	2.5	5.0	5.5	V
$V_{DDA}$	Analog Operating Voltage	—	2.5	5.0	5.5	V

## On-Chip LDO Voltage Regulator Characteristics

**Table 11. LDO Characteristics**

$T_A = 25\text{ }^\circ\text{C}$ , unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$V_{LDO}$	Internal Regulator Output Voltage	$V_{DD} \geq 2.5\text{ V}$ Regulator input @ $I_{LDO} = 35\text{ mA}$ and voltage variation = $\pm 5\%$ , After trimming	1.425	1.5	1.57	V
$I_{LDO}$	Output Current	$V_{DD} = 2.5\text{ V}$ Regulator input, @ $V_{LDO} = 1.5\text{ V}$	—	30	35	mA
$C_{LDO}$	External Filter Capacitor Value for Internal Core Power Supply	The capacitor value is dependent on the core power current consumption	1	2.2	—	$\mu\text{F}$

## Power Consumption

The current consumption is influenced by several parameters and factors, including the operating voltage, ambient temperature, I/O pin loading, device software configuration, operating frequencies, I/O pin switching rate, program location in memory and executed binary code.

The MCU is configured under the following conditions for current consumption measured:

- All I/O pins are set to a high-impedance (floating) state.
- All peripherals are disabled unless specifically stated otherwise.
- The Flash memory access time is optimized using the minimum wait states number, depending on the  $f_{HCLK}$  frequency.
- When the peripherals are enabled,  $f_{PCLK} = f_{HCLK}$ .

**Table 12. Power Consumption Characteristics**

$T_A = 25\text{ }^\circ\text{C}$ , unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$I_{DD}$	Supply Current (Run Mode)	$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL = 60 MHz, $f_{HCLK} = 60\text{ MHz}$ , $f_{PCLK} = 60\text{ MHz}$ , all peripherals enabled	—	16.76	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL = 60 MHz, $f_{HCLK} = 60\text{ MHz}$ , $f_{PCLK} = 60\text{ MHz}$ , all peripherals disabled	—	7.54	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL = 40 MHz, $f_{HCLK} = 40\text{ MHz}$ , $f_{PCLK} = 40\text{ MHz}$ , all peripherals enabled	—	13.9	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL = 40 MHz, $f_{HCLK} = 40\text{ MHz}$ , $f_{PCLK} = 40\text{ MHz}$ , all peripherals disabled	—	7.69	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL = 20 MHz, $f_{HCLK} = 20\text{ MHz}$ , $f_{PCLK} = 20\text{ MHz}$ , all peripherals enabled	—	6.56	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL = 20 MHz, $f_{HCLK} = 20\text{ MHz}$ , $f_{PCLK} = 20\text{ MHz}$ , all peripherals disabled	—	3.44	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL off, $f_{HCLK} = 8\text{ MHz}$ , $f_{PCLK} = 8\text{ MHz}$ , all peripherals enabled	—	2.69	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL off, $f_{HCLK} = 8\text{ MHz}$ , $f_{PCLK} = 8\text{ MHz}$ , all peripherals disabled	—	1.43	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI off, PLL off, LSI on, $f_{HCLK} = 32\text{ kHz}$ , $f_{PCLK} = 32\text{ kHz}$ , all peripherals enabled	—	34.6	—	$\mu\text{A}$
		$V_{DD} = 5.0\text{ V}$ , HSI off, PLL off, LSI on, $f_{HCLK} = 32\text{ kHz}$ , $f_{PCLK} = 32\text{ kHz}$ , all peripherals disabled	—	29.6	—	$\mu\text{A}$
	Supply Current (Sleep Mode)	$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL = 60 MHz, $f_{HCLK} = 0\text{ MHz}$ , $f_{PCLK} = 60\text{ MHz}$ , all peripherals enabled	—	11.22	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL = 60 MHz, $f_{HCLK} = 0\text{ MHz}$ , $f_{PCLK} = 60\text{ MHz}$ , all peripherals disabled	—	1.19	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL = 40 MHz, $f_{HCLK} = 0\text{ MHz}$ , $f_{PCLK} = 40\text{ MHz}$ , all peripherals enabled	—	7.63	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL = 40 MHz, $f_{HCLK} = 0\text{ MHz}$ , $f_{PCLK} = 40\text{ MHz}$ , all peripherals disabled	—	0.94	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL = 20 MHz, $f_{HCLK} = 0\text{ MHz}$ , $f_{PCLK} = 20\text{ MHz}$ , all peripherals enabled	—	4.16	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL = 20 MHz, $f_{HCLK} = 0\text{ MHz}$ , $f_{PCLK} = 20\text{ MHz}$ , all peripherals disabled	—	0.73	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL off, $f_{HCLK} = 0\text{ MHz}$ , $f_{PCLK} = 8\text{ MHz}$ , all peripherals enabled	—	1.72	—	mA
		$V_{DD} = 5.0\text{ V}$ , HSI = 8 MHz, PLL off, $f_{HCLK} = 0\text{ MHz}$ , $f_{PCLK} = 8\text{ MHz}$ , all peripherals disabled	—	0.35	—	mA

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$I_{DD}$	Supply Current (Deep-Sleep Mode)	$V_{DD} = 5.0$ V, all clock off (HSE/HSI), LDO in low power mode, LSI on, LSTM on	—	25	—	$\mu$ A

Note: 1. HSE means high speed external oscillator. HSI means 8 MHz high speed internal oscillator.  
2. LSI means 32 kHz low speed internal oscillator.  
3. Code = while (1) { 208 NOP } executed in Flash.

## Reset and Supply Monitor Characteristics

**Table 13.  $V_{DD}$  Power Reset Characteristics**

$T_A = 25$  °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$V_{POR}$	Power On Reset Threshold (Rising Voltage on $V_{DD}$ )	$T_A = -40$ °C ~ $105$ °C	2.22	2.35	2.48	V
$V_{PDR}$	Power Down Reset Threshold (Falling Voltage on $V_{DD}$ )		2.09	2.20	2.33	V
$V_{PORHYST}$	POR Hysteresis	—	—	150	—	mV
$t_{POR}$	Reset Delay Time	$V_{DD} = 5.0$ V	—	0.1	0.2	ms

Note: 1. Data based on characterization results only, not tested in production.  
2. If the LDO is turned on, the  $V_{DD}$  POR has to be in the de-assertion condition. When the  $V_{DD}$  POR is in the assertion state then the LDO will be turned off.

**Table 14. LVD / BOD Characteristics**

$T_A = 25$  °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit	
$V_{BOD}$	Voltage of Brown-Out Detection	After factory-trimmed, $V_{DD}$ Falling edge	2.37	2.45	2.53	V	
$V_{LVD}$	Voltage of Low Voltage Detection	$V_{DD}$ Falling edge	LVDS = 000	2.57	2.65	2.73	V
			LVDS = 001	2.77	2.85	2.93	V
			LVDS = 010	2.97	3.05	3.13	V
			LVDS = 011	3.17	3.25	3.33	V
			LVDS = 100	3.37	3.45	3.53	V
			LVDS = 101	4.15	4.25	4.35	V
			LVDS = 110	4.35	4.45	4.55	V
			LVDS = 111	4.55	4.65	4.75	V
$V_{LVDHTST}$	LVD Hysteresis	$V_{DD} = 5.0$ V	—	—	100	mV	
$t_{suLVD}$	LVD Setup Time	$V_{DD} = 5.0$ V	—	—	5	$\mu$ s	
$t_{alLVD}$	LVD Active Delay Time	$V_{DD} = 5.0$ V	—	—	—	ms	
$I_{DDLVD}$	Operation Current <sup>(2)</sup>	$V_{DD} = 5.0$ V	—	—	10	$\mu$ A	

Note: 1. Data based on characterization results only, not tested in production.  
2. Bandgap current is not included.  
3. LVDS field is in the PWRCU LVDCSR register.

## External Clock Characteristics

**Table 15. High Speed External Clock (HSE) Characteristics**

$T_A = 25\text{ }^\circ\text{C}$ , unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$V_{DD}$	Operation Voltage Range	—	2.5	—	5.5	V
$f_{HSE}$	HSE Frequency	—	4	—	16	MHz
$C_L$	Load Capacitance	$V_{DD} = 5.0\text{ V}$ , $R_{ESR} = 100\ \Omega$ @ 16 MHz	—	—	22	pF
$R_{FHSE}$	Internal Feedback Resistor between XTALIN and XTALOUT pins	—	—	0.5	—	M $\Omega$
$R_{ESR}$	Equivalent Series Resistance	$V_{DD} = 5.0\text{ V}$ , $C_L = 12\text{ pF}$ @ 16 MHz, HSEGAIN = 0 $V_{DD} = 2.5\text{ V}$ , $C_L = 12\text{ pF}$ @ 16 MHz, HSEGAIN = 1	—	—	160	$\Omega$
$D_{HSE}$	HSE Oscillator Duty Cycle	—	40	—	60	%
$I_{DDHSE}$	HSE Oscillator Current Consumption	$V_{DD} = 5.0\text{ V}$ @ 16 MHz	—	TBD	—	mA
$I_{PVDHSE}$	HSE Oscillator Power Down Current	$V_{DD} = 5.0\text{ V}$	—	—	0.01	$\mu\text{A}$
$t_{SUHSE}$	HSE Oscillator Startup Time	$V_{DD} = 5.0\text{ V}$	—	—	4	ms

## Internal Clock Characteristics

**Table 16. High Speed Internal Clock (HSI) Characteristics**

$T_A = 25\text{ }^\circ\text{C}$ , unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$V_{DD}$	Operation Voltage Range	$T_A = -40\text{ }^\circ\text{C} \sim 105\text{ }^\circ\text{C}$	2.5	—	5.5	V
$f_{HSI}$	HSI Frequency	$V_{DD} = 5.0\text{ V}$ @ 25 $^\circ\text{C}$	—	8	—	MHz
$ACC_{HSI}$	Factory Calibrated HSI Oscillator Frequency Accuracy	$V_{DD} = 5.0\text{ V}$ , $T_A = 25\text{ }^\circ\text{C}$	-2	—	+2	%
		$V_{DD} = 2.5\text{ V} \sim 5.5\text{ V}$ $T_A = -20\text{ }^\circ\text{C} \sim 85\text{ }^\circ\text{C}$	-3	—	+3	%
		$V_{DD} = 2.5\text{ V} \sim 5.5\text{ V}$ $T_A = 85\text{ }^\circ\text{C} \sim 105\text{ }^\circ\text{C}$ or $T_A = -40\text{ }^\circ\text{C} \sim -20\text{ }^\circ\text{C}$	-3.5	—	+3.5	%
Duty	Duty Cycle	$f_{HSI} = 8\text{ MHz}$	35	—	65	%
$I_{DDHSI}$	Oscillator Supply Current	$f_{HSI} = 8\text{ MHz}$	—	300	500	$\mu\text{A}$
	Power Down Current		—	—	0.05	
$t_{SUHSI}$	HSI Oscillator Startup Time	$f_{HSI} = 8\text{ MHz}$	—	—	10	$\mu\text{s}$

**Table 17. Low Speed Internal Clock (LSI) Characteristics**

$T_A = 25\text{ }^\circ\text{C}$ , unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$V_{DD}$	Operation Voltage Range	—	2.5	—	5.5	V
$f_{LSI}$	LSI Frequency	$V_{DD} = 5.0\text{ V}$ , $T_A = -40\text{ }^\circ\text{C} \sim 105\text{ }^\circ\text{C}$	21	32	43	kHz
$ACC_{LSI}$	LSI Frequency Accuracy	After factory-trimmed, $V_{DD} = 5.0\text{ V}$ , $T_A = 25\text{ }^\circ\text{C}$	-10	—	+10	%
$I_{DDL SI}$	LSI Oscillator Operating Current	$V_{DD} = 5.0\text{ V}$ , $T_A = 25\text{ }^\circ\text{C}$	—	0.4	0.8	$\mu\text{A}$
$t_{SULSI}$	LSI Oscillator Startup Time	$V_{DD} = 5.0\text{ V}$ , $T_A = 25\text{ }^\circ\text{C}$	—	—	100	$\mu\text{s}$

## System PLL Characteristics

Table 18. System PLL Characteristics

$T_A = 25\text{ }^\circ\text{C}$ , unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$f_{\text{PLLIN}}$	System PLL Input Clock	—	4	—	16	MHz
$f_{\text{CK\_PLL}}$	System PLL Output Clock	—	16	—	60	MHz
$t_{\text{LOCK}}$	System PLL Lock Time	—	—	200	—	$\mu\text{s}$

## Memory Characteristics

Table 19. Flash Memory Characteristics

$T_A = 25\text{ }^\circ\text{C}$ , unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$N_{\text{ENDU}}$	Number of Guaranteed Program / Erase Cycles before failure (Endurance)	$T_A = -40\text{ }^\circ\text{C} \sim 105\text{ }^\circ\text{C}$	20	—	—	K cycles
$t_{\text{RET}}$	Data Retention Time	$T_A = -40\text{ }^\circ\text{C} \sim 105\text{ }^\circ\text{C}$	10	—	—	Years
$t_{\text{PROG}}$	Word Programming Time	$T_A = -40\text{ }^\circ\text{C} \sim 105\text{ }^\circ\text{C}$	20	—	—	$\mu\text{s}$
$t_{\text{ERASE}}$	Page Erase Time	$T_A = -40\text{ }^\circ\text{C} \sim 105\text{ }^\circ\text{C}$	2	—	—	ms
$t_{\text{MERASE}}$	Mass Erase Time	$T_A = -40\text{ }^\circ\text{C} \sim 105\text{ }^\circ\text{C}$	10	—	—	ms

## I/O Port Characteristics

Table 20. I/O Port Characteristics

$T_A = 25\text{ }^\circ\text{C}$ , unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit	
$I_{\text{IL}}$	Low Level Input Current	5.0 V I/O	$V_i = V_{\text{SS}}$ , On-chip pull-up resistor disabled	—	—	3	$\mu\text{A}$
		Reset pin		—	—	3	
$I_{\text{IH}}$	High Level Input Current	5.0 V I/O	$V_i = V_{\text{DD}}$ , On-chip pull-down resistor disabled	—	—	3	$\mu\text{A}$
		Reset pin		—	—	3	
$V_{\text{IL}}$	Low Level Input Voltage	5.0 V I/O	—	—	$0.35 \times V_{\text{DD}}$	V	
		Reset pin	-0.5	—	$0.35 \times V_{\text{DD}}$		
$V_{\text{IH}}$	High Level Input Voltage	5.0 V I/O	$0.65 \times V_{\text{DD}}$	—	$V_{\text{DD}} + 0.5$	V	
		Reset pin	$0.65 \times V_{\text{DD}}$	—	$V_{\text{DD}} + 0.5$		
$V_{\text{HYS}}$	Schmitt Trigger Input Voltage Hysteresis	5.0 V I/O	—	$0.12 \times V_{\text{DD}}$	—	mV	
		Reset pin	—	$0.12 \times V_{\text{DD}}$	—		
$I_{\text{OL}}$	Low Level Output Current (GPIO Sink Current)	5.0 V I/O 4 mA drive, $V_{\text{OL}} = 0.4\text{ V}$	4	—	—	mA	
		5.0 V I/O 8 mA drive, $V_{\text{OL}} = 0.4\text{ V}$	8	—	—	mA	
		5.0 V I/O 12 mA drive, $V_{\text{OL}} = 0.4\text{ V}$	12	—	—	mA	
		5.0 V I/O 16 mA drive, $V_{\text{OL}} = 0.4\text{ V}$	16	—	—	mA	
		$V_{\text{DD}}$ Domain I/O drive @ $V_{\text{DD}} = 5.0\text{ V}$ , $V_{\text{OL}} = 0.4\text{ V}$ , PB10, PB11	4	—	—	mA	

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
I <sub>OH</sub>	High Level Output Current (GPIO Source Current)	5.0 V I/O 4 mA drive, V <sub>OH</sub> = V <sub>DD</sub> - 0.4 V	4	—	—	mA
		5.0 V I/O 8 mA drive, V <sub>OH</sub> = V <sub>DD</sub> - 0.4 V	8	—	—	mA
		5.0 V I/O 12 mA drive, V <sub>OH</sub> = V <sub>DD</sub> - 0.4 V	12	—	—	mA
		5.0 V I/O 16 mA drive, V <sub>OH</sub> = V <sub>DD</sub> - 0.4 V	16	—	—	mA
		V <sub>DD</sub> Domain I/O drive @ V <sub>DD</sub> = 5.0 V, V <sub>OH</sub> = V <sub>DD</sub> - 0.4 V, PB10, PB11	—	—	2	mA
V <sub>OL</sub>	Low Level Output Voltage	5.0 V 4 mA drive I/O, I <sub>OL</sub> = 4 mA	—	—	0.4	V
		5.0 V 8 mA drive I/O, I <sub>OL</sub> = 8 mA	—	—	0.4	
		5.0 V 12 mA drive I/O, I <sub>OL</sub> = 12 mA	—	—	0.4	
		5.0 V 16 mA drive I/O, I <sub>OL</sub> = 16 mA	—	—	0.4	
V <sub>OH</sub>	High Level Output Voltage	5.0 V 4 mA drive I/O, I <sub>OH</sub> = 4 mA	V <sub>DD</sub> - 0.4	—	—	V
		5.0 V 8 mA drive I/O, I <sub>OH</sub> = 8 mA	V <sub>DD</sub> - 0.4	—	—	
		5.0 V 12 mA drive I/O, I <sub>OH</sub> = 12 mA	V <sub>DD</sub> - 0.4	—	—	
		5.0 V 16 mA drive I/O, I <sub>OH</sub> = 16 mA	V <sub>DD</sub> - 0.4	—	—	
R <sub>PU</sub>	Internal Pull-up Resistor	5.0 V I/O, V <sub>DD</sub> = 5.0 V	—	60	—	kΩ
R <sub>PD</sub>	Internal Pull-down Resistor	5.0 V I/O, V <sub>DD</sub> = 5.0 V	—	60	—	kΩ

## ADC Characteristics

Table 21. ADC Characteristics

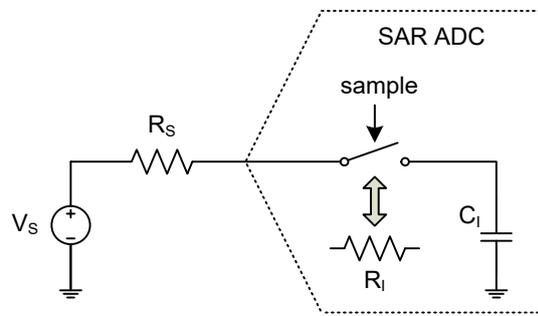
T<sub>A</sub> = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V <sub>DDA</sub>	A/D Converter Operating Voltage	—	2.5	5.0	5.5	V
V <sub>ADCIN</sub>	A/D Converter Input Voltage Range	—	0	—	V <sub>REF+</sub>	V
V <sub>REF+</sub>	A/D Converter Reference Voltage	—	—	V <sub>DDA</sub>	V <sub>DDA</sub>	V
I <sub>ADC</sub>	A/D Converter Operating Current	V <sub>DDA</sub> = 5.0 V	—	0.85	1	mA
I <sub>ADC_DN</sub>	Power Down Current Consumption	V <sub>DDA</sub> = 5.0 V	—	—	0.1	μA
f <sub>ADC</sub>	A/D Converter Clock Frequency	—	0.7	—	32	MHz
f <sub>S</sub>	Sampling Rate	—	0.05	—	2	Msp/s
t <sub>DL</sub>	Data Latency	—	—	12.5	—	1/f <sub>ADC</sub> Cycles
t <sub>S&amp;H</sub>	Sampling & Hold Time	—	—	3.5	—	1/f <sub>ADC</sub> Cycles
t <sub>ADCCONV</sub>	A/D Converter Conversion Time	ADST[7:0] = 2	—	16	—	1/f <sub>ADC</sub> Cycles
R <sub>I</sub>	Input Sampling Switch Resistance	—	—	—	1	kΩ
C <sub>I</sub>	Input Sampling Capacitance	No pin/pad capacitance included	—	16	—	pF
t <sub>SU</sub>	Startup Time	—	—	—	1	μs
N	Resolution	—	—	12	—	bits
INL	Integral Non-linearity Error	f <sub>S</sub> = 750 ksps, V <sub>DDA</sub> = 5.0 V	—	—	±2	LSB

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
DNL	Differential Non-linearity Error	$f_s = 750 \text{ ksp/s}$ , $V_{DDA} = 5.0 \text{ V}$	—	—	$\pm 1$	LSB
$E_o$	Offset Error	—	—	—	$\pm 10$	LSB
$E_G$	Gain Error	—	—	—	$\pm 10$	LSB

Note: 1. Data based on characterization results only, not tested in production.

- Due to the A/D Converter input channel and GPIO pin-shared function design limitation, the  $V_{DDA}$  supply power of the A/D Converter has to be equal to the  $V_{DD}$  supply power of the MCU in the application circuit.
- The figure below shows the equivalent circuit of the A/D Converter Sample-and-Hold input stage where  $C_1$  is the storage capacitor,  $R_1$  is the resistance of the sampling switch and  $R_s$  is the output impedance of the signal source  $V_s$ . Normally the sampling phase duration is approximately,  $3.5/f_{ADC}$ . The capacitance,  $C_1$ , must be charged within this time frame and it must be ensured that the voltage at its terminals becomes sufficiently close to  $V_s$  for accuracy. To guarantee this,  $R_s$  is not allowed to have an arbitrarily large value.



**Figure 11. ADC Sampling Network Model**

The worst case occurs when the extremities of the input range (0 V and  $V_{REF}$ ) are sampled consecutively. In this situation a sampling error below  $\frac{1}{4}$  LSB is ensured by using the following equation:

$$R_s < \frac{3.5}{f_{ADC} C_1 \ln(2^{N+2})} - R_1$$

Where  $f_{ADC}$  is the ADC clock frequency and  $N$  is the ADC resolution ( $N = 12$  in this case). A safe margin should be considered due to the pin/pad parasitic capacitances, which are not accounted for in this simple model.

If, in a system where the A/D Converter is used, there are no rail-to-rail input voltage variations between consecutive sampling phases,  $R_s$  may be larger than the value indicated by the equation above.

## Comparator Characteristics

**Table 22. Comparator Characteristics**

$T_A = 25 \text{ }^\circ\text{C}$ , unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$V_{DDA}$	Operating Voltage	Comparator mode	2.5	5.0	5.5	V
$V_{IN}$	Input Common Mode Voltage Range	CP or CN	$V_{SSA}$	—	$V_{DDA}$	V
$V_{IOS}$	Input Offset Voltage <sup>(Note)</sup>	—	-15	—	15	mV

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit	
V <sub>HYS</sub>	Input Hysteresis V <sub>DDA</sub> = 5.0 V	No hysteresis, CMPHM [1:0] = 00	—	0	—	mV	
		Low hysteresis, CMPHM [1:0] = 01	—	30	—	mV	
		Middle hysteresis, CMPHM [1:0] = 10	—	60	—	mV	
		High hysteresis, CMPHM [1:0] = 11	—	100	—	mV	
t <sub>RT</sub>	Response Time Input Overdrive = ±100 mV	High Speed Mode	V <sub>DDA</sub> ≥ 2.7 V	—	50	100	ns
			V <sub>DDA</sub> < 2.7 V	—	100	250	
		Low Speed Mode		—	2	5	μs
I <sub>COMP</sub>	Current Consumption V <sub>DDA</sub> = 5.0 V	High Speed Mode		—	180	—	μA
		Low Speed Mode		—	30	—	μA
t <sub>COMPST</sub>	Comparator Startup Time	Comparator enabled to output valid	—	—	50	μs	
I <sub>COMP_DN</sub>	Power Down Supply Current	CMPEN = 0, CVREN = 0, CVROE = 0	—	—	0.1	μA	
<b>Comparator Voltage Reference (CVR)</b>							
V <sub>CVR</sub>	Output Range	—	V <sub>SSA</sub>	—	V <sub>DDA</sub>	V	
N <sub>Bits</sub>	CVR Scaler Resolution	—	—	8	—	bits	
t <sub>CVRST</sub>	Settling Time	CVR Scaler Settling Time from CVRVAL = "00000000" to "11111111"	—	—	100	μs	
I <sub>CVR</sub>	Current Consumption V <sub>DDA</sub> = 5.0 V	CVREN = 1, CVROE = 0	—	65	—	μA	
		CVREN = 1, CVROE = 1	—	80	110	μA	

Note: Data based on characterization results only, not tested in production.

## Operational Amplifier Characteristics

**Table 23. Operational Amplifier Characteristics**

T<sub>A</sub> = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V <sub>DDA</sub>	Operating Voltage	OPA mode	3.0	5.0	5.5	V
I <sub>OPA_DN</sub>	Power Down Current	—	—	—	0.1	μA
I <sub>OPA</sub>	Operating Current	V <sub>DD</sub> = 5 V	—	800	—	μA
V <sub>OS</sub>	Input Offset Voltage	Without calibration (OOF[4:0] = 10000B)	-15	—	15	mV
		With calibration	-2	—	2	
V <sub>OR</sub>	Maximum Output Voltage Range	—	V <sub>SS</sub> + 0.2	—	V <sub>DD</sub> - 0.2	V
I <sub>OS</sub>	Input Offset Current	V <sub>IN</sub> = 1/2V <sub>CM</sub>	—	1	10	nA
PSRR	Power Supply Rejection Ratio	—	—	60	—	dB
CMRR	Common Mode Rejection Ratio	V <sub>CM</sub> = 0 ~ V <sub>DD</sub> - 1.4	—	60	—	dB
SR	Slew Rate+, Slew Rate-	R <sub>L</sub> = 100 kΩ, C <sub>L</sub> = 50 pF	—	6	—	V/μs
GBW	Gain Band Width	R <sub>L</sub> = 100 kΩ, C <sub>L</sub> = 50 pF	—	6	—	MHz
A <sub>OL</sub>	Open Loop Gain	R <sub>L</sub> = 100 kΩ, C <sub>L</sub> = 50 pF	60	80	—	dB
PM	Phase Margin	R <sub>L</sub> = 100 kΩ, C <sub>L</sub> = 50 pF	50	60	—	Deg
V <sub>CM</sub>	Common Mode Voltage Range	—	V <sub>SS</sub>	—	V <sub>DD</sub> - 1.4	V

## MCTM / GPTM / SCTM Characteristics

Table 24. MCTM / GPTM / SCTM Characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$f_{TM}$	Timer Clock Source for MCTM, GPTM and SCTM	—	—	—	$f_{PCLK}$	MHz
$t_{RES}$	Timer Resolution Time	—	1	—	—	$1/f_{TM}$
$f_{EXT}$	External Signal Frequency on Channel 0 ~ 3	—	—	—	1/2	$f_{TM}$
RES	Timer Resolution	—	—	—	16	bits

## Gate-Driver Characteristics

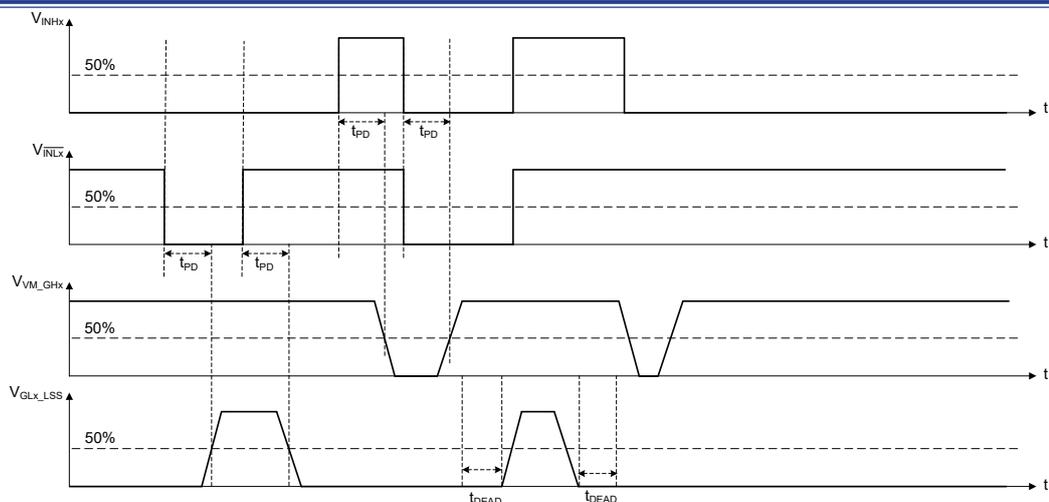
$V_{CC} = V_M = 24\text{ V}$ ,  $C_1 = 4.7\ \mu\text{F}$ ,  $C_2 = 2.2\ \mu\text{F}$  and  $T_A = +25\text{ }^\circ\text{C}$ , unless otherwise specified

Table 25. Gate-Driver Characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
<b>Power Supply/Regulators</b>						
$V_{CC}$	Supply Voltage	—	6	—	32	V
$I_{CC}$	Supply Standby Current	LDOEN = '1', $V_{REG}$ with no load	—	18	25	$\mu\text{A}$
$I_{CC(SLP)}$	Supply Sleep Current	LDOEN = '0'	—	—	1	$\mu\text{A}$
$V_{REG}$	VREG Output Voltage	$I_{LOAD} = 1\text{ mA}$	4.925	5.000	5.075	V
$I_{LOAD}^{(1)}$	VREG Output Current	$V_{CC} = (V_{REG} + 1)$ to 32 V (without thermal limited)	50	—	—	mA
$\Delta V_{REG}$	VREG Load Regulation	$I_{LOAD} = 0$ to 30 mA	—	15	—	mV
$\frac{\Delta V_{REG}}{\Delta V_{CC} \times V_{REG}}$	VREG Linear Regulation	$V_{CC} = (V_{REG} + 1)$ to 32 V	—	0.1	0.2	% / V
$\frac{\Delta V_{REG}}{\Delta T_A \times V_{REG}}$	VREG Temperature Coefficient	$I_{LOAD} = 1\text{ mA}$ , $T_A = -40\text{ }^\circ\text{C}$ to $105\text{ }^\circ\text{C}$	—	$\pm 100$	—	ppm / $^\circ\text{C}$
PSRR	VREG Power Supply Rejection Ratio	$I_{LOAD} = 30\text{ mA}$	—	60	—	dB
Noise	VREG Output Noise	$I_{LOAD} = 30\text{ mA}$ , BW = 10 ~ 100 kHz	—	50	—	$\mu\text{V}_{RMS}$
$R_{DIS}$	VREG Discharging Resistance	LDOEN = '0'	—	400	—	$\Omega$
$t_{SLPDB}$	Sleep Trigger Debounce Time	—	—	3.4	—	$\mu\text{s}$
<b>Gate-Driver (GHx, GLx)</b>						
$V_{SGH}$	High-Side $V_{SG}$ Gate Drive $V_{(VM, GHx)}$	$V_M < 12\text{ V}$ , $f_{PWM} = 25\text{ kHz}^{(2)}$	—	$V_M - 0.8$	—	V
		$V_M = 12\text{ V}$ to 32 V, $f_{PWM} = 25\text{ kHz}^{(2)}$	—	12	—	
$V_{GSL}$	Low-Side $V_{GS}$ Gate Drive $V_{(GLx, LSS)}$	$V_M < 12\text{ V}$ , $f_{PWM} = 25\text{ kHz}^{(2)}$	—	$V_M - 0.9$	—	V
		$V_M = 12\text{ V}$ to 32 V, $f_{PWM} = 25\text{ kHz}^{(2)}$	—	12	—	
$I_{DRVP}$	High-Side and Low-Side Gate Peak Source Current	$C_{LOAD} = 200\text{ nF}$	—	350	—	mA
$I_{DRVN}$	High-Side and Low-Side Gate Peak Sink Current	$C_{LOAD} = 200\text{ nF}$	—	500	—	mA
$t_{DEAD}$	Dead Time	—	—	120	200	ns
$t_{DEAD\_MIS}$	Dead Time Mismatch	Dead time difference between rising and falling edges	—	50	—	ns
$t_{PD}$	Propagation Delay	INHx to GHx and INLx to GLx transition (No connected capacitor with GHx/GLx)	—	160	250	ns

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$t_{PD\_MIS}$	High-Side / Low-Side Propagation delay mismatch	Propagation delay difference between different phase or different side	—	80	—	ns
$R_{OFF1}$	Low-Side Gate Hold-off Resistor	GLx to PGND	—	100	—	k $\Omega$
$R_{OFF2}$	High-Side Gate Hold-off Resistor	VM to GHx	—	100	—	k $\Omega$
<b>Protections</b>						
$V_{CC\_UVLO+}$	$V_{CC}$ Turn On Level	$V_{CC}$ rises	—	—	4.5	V
$V_{CC\_UVLO-}$	$V_{CC}$ Turn Off Level	$V_{CC}$ falls	3.5	—	—	V
$V_{REG\_UVLO+}$	$V_{REG}$ Turn On Level	$V_{REG}$ rises	—	—	4.0	V
$V_{REG\_UVLO-}$	$V_{REG}$ Turn Off Level	$V_{REG}$ falls	3.0	—	—	V
<b>Control Logic</b>						
$I_{FG}$	FG Leakage Current	FGI is low level. $V_{FG} = 24$ V	—	—	0.5	$\mu$ A
$V_{OL\_FG}$	FG Output Low Voltage	FGI is high level, 5 mA source current	—	0.15	0.40	V
$R_{PD1}$	Input Logic Pull-down Resistor 1	INLx	—	100	—	k $\Omega$
$R_{PD2}$	Input Logic Pull-down Resistor 2	LDOEN	—	10	—	k $\Omega$
<b>External Wake-up</b>						
$V_{WKTH}$	WKI Trigger Threshold Voltage	—	2	—	4	V
$t_{WKDB1}$	Debounce Time between WKI Input being Triggered to LDO Wake-up	—	1	—	—	ms
$t_{WKDB2}$	Debounce Time between WKI Input being Triggered and WKO output	—	10	—	—	$\mu$ s
$I_{WKI}$	WKI Input Current	$V_{WKI} = 32$ V	—	50	—	$\mu$ A
<b>Voltage Divider</b>						
$V_{DIV}$	Power Supply Voltage Divider VDC Line Output Voltage	LDOEN = '1'	2.85	3.00	3.15	V
$R_{DIV}$	Power Supply Voltage Divider Resistor	LDOEN = '0', disable voltage divider	—	8	—	k $\Omega$

Note: 1. Output current standard: the output voltage might keep a 2% voltage drop compared to the original output voltage for a 1 mA load current.  
2.  $f_{PWM}$  is the frequency of the PWM signal output by the MCU to the gate-driver.



**Figure 12. Gate-Driver Timing**

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

Table 26. I<sup>2</sup>C Characteristics

Symbol	Parameter	Standard Mode		Fast Mode		Fast Plus Mode		Unit
		Min.	Max.	Min.	Max.	Min.	Max.	
f <sub>SCL</sub>	SCL Clock Frequency	—	100	—	400	—	1000	kHz
t <sub>SCL(H)</sub>	SCL Clock High Time	4.5	—	1.125	—	0.45	—	μs
t <sub>SCL(L)</sub>	SCL Clock Low Time	4.5	—	1.125	—	0.45	—	μs
t <sub>FALL</sub>	SCL And SDA Fall Time	—	1.3	—	0.34	—	0.135	μs
t <sub>RISE</sub>	SCL And SDA Rise Time	—	1.3	—	0.34	—	0.135	μs
t <sub>SU(SDA)</sub>	SDA Data Setup Time	500	—	125	—	50	—	ns
t <sub>H(SDA)</sub>	SDA Data Hold Time <sup>(5)</sup>	0	—	0	—	0	—	ns
	SDA Data Hold Time <sup>(6)</sup>	100	—	100	—	100	—	ns
t <sub>VD(SDA)</sub>	SDA Data Valid Time	—	1.6	—	0.475	—	0.25	μs
t <sub>SU(STA)</sub>	START Condition Setup Time	500	—	125	—	50	—	ns
t <sub>H(STA)</sub>	START Condition Hold Time	0	—	0	—	0	—	ns
t <sub>SU(STO)</sub>	STOP Condition Setup Time	500	—	125	—	50	—	ns

Note: 1. Data based on characterization results only, not tested in production.

2. To achieve 100 kHz standard mode, the peripheral clock frequency must be higher than 2 MHz.

3. To achieve 400 kHz fast mode, the peripheral clock frequency must be higher than 8 MHz.

4. To achieve 1 MHz fast plus mode, the peripheral clock frequency must be higher than 20 MHz.

5. The above characteristic parameters of the I<sup>2</sup>C bus timing are based on: COMBFILTEREN = 0 and SEQFILTER = 00.

6. The above characteristic parameters of the I<sup>2</sup>C bus timing are based on: COMBFILTEREN = 1 and SEQFILTER = 00.

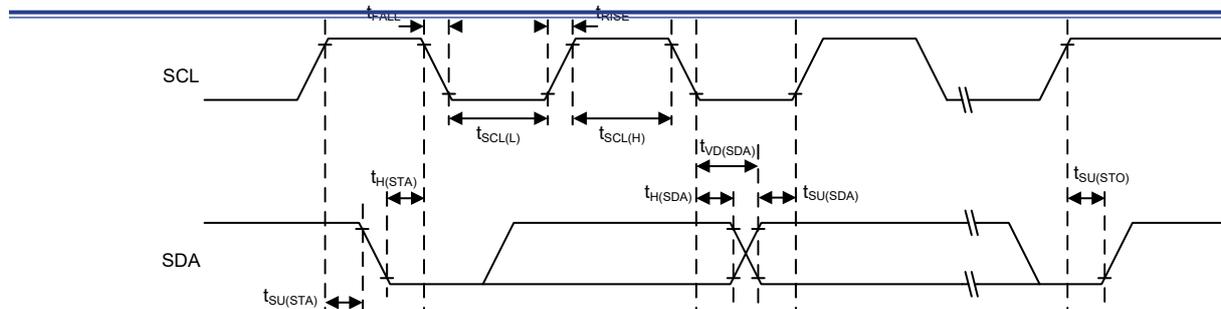


Figure 13. I<sup>2</sup>C Timing Diagram

## SPI Characteristics

**Table 27. SPI Characteristics**

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
<b>SPI Master Mode</b>						
$f_{SCK}$	SPI Master Output SCK Clock Frequency	Master mode, SPI peripheral clock frequency $f_{PCLK}$	—	—	$f_{PCLK}/2$	MHz
$t_{SCK(H)}$ $t_{SCK(L)}$	SCK Clock High and Low Time	—	$t_{SCK}/2 - 2$	—	$t_{SCK}/2 + 1$	ns
$t_{V(MO)}$	Data Output Valid Time	—	—	—	5	ns
$t_{H(MO)}$	Data Output Hold Time	—	2	—	—	ns
$t_{SU(MI)}$	Data Input Setup Time	—	5	—	—	ns
$t_{H(MI)}$	Data Input Hold Time	—	5	—	—	ns
<b>SPI Slave Mode</b>						
$f_{SCK}$	SPI Slave Input SCK Clock Frequency	Slave mode, SPI peripheral clock frequency $f_{PCLK}$	—	—	$f_{PCLK}/3$	MHz
Duty <sub>SCK</sub>	SPI Slave Input SCK Clock Duty Cycle	—	30	—	70	%
$t_{SU(SEL)}$	SEL Enable Setup Time	—	$3 t_{PCLK}$	—	—	ns
$t_{H(SEL)}$	SEL Enable Hold Time	—	$2 t_{PCLK}$	—	—	ns
$t_{A(SO)}$	Data Output Access Time	—	—	—	$3 t_{PCLK}$	ns
$t_{DIS(SO)}$	Data Output Disable Time	—	—	—	10	ns
$t_{V(SO)}$	Data Output Valid Time	—	—	—	25	ns
$t_{H(SO)}$	Data Output Hold Time	—	15	—	—	ns
$t_{SU(SI)}$	Data Input Setup Time	—	5	—	—	ns
$t_{H(SI)}$	Data Input Hold Time	—	4	—	—	ns

Note: 1.  $f_{SCK}$  is SPI output/input clock frequency and  $t_{SCK} = 1/f_{SCK}$ .  
2.  $f_{PCLK}$  is SPI peripheral clock frequency and  $t_{PCLK} = 1/f_{PCLK}$ .

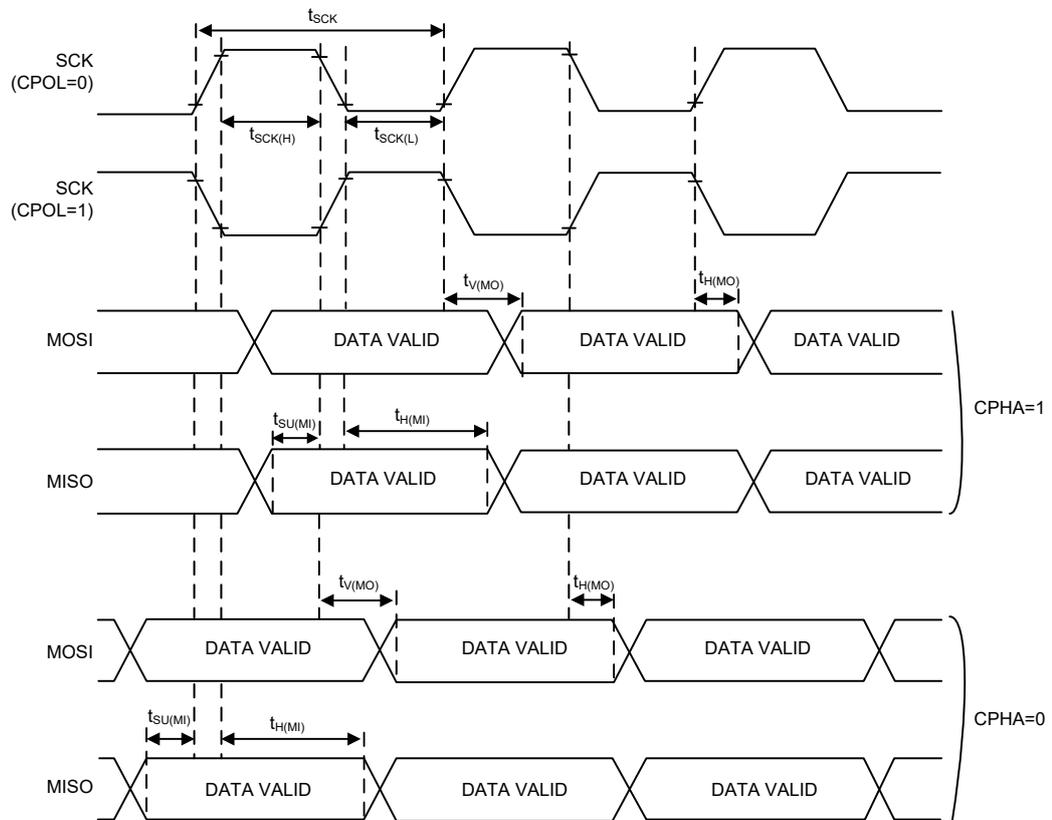


Figure 14. SPI Timing Diagram – SPI Master Mode

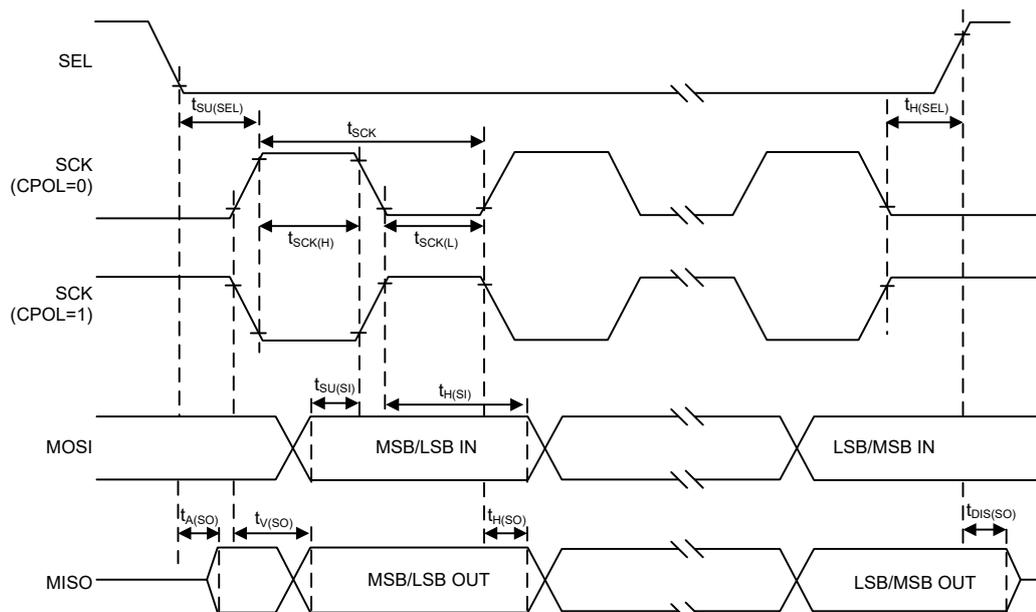


Figure 15. SPI Timing Diagram – SPI Slave Mode with CPHA = 1

## 8 Package Information

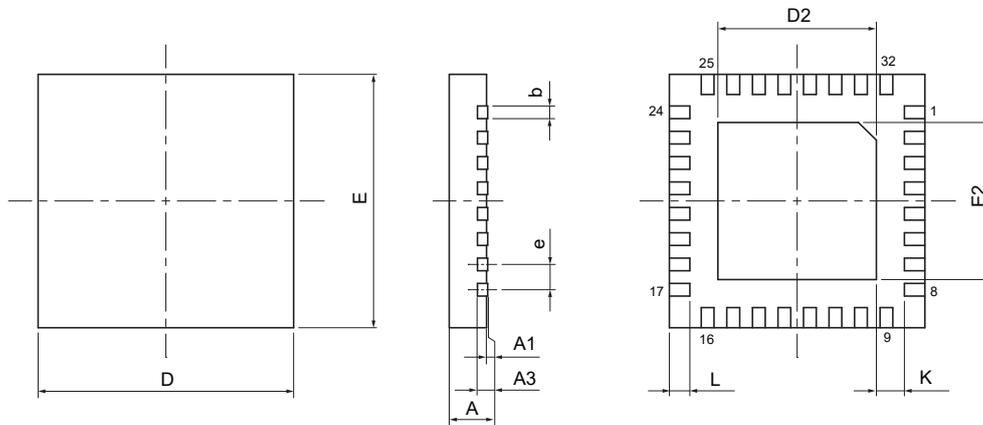
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Note that the package information provided here is for consultation purposes only. As this information may be updated at regular intervals users are reminded to consult the [Holtek website](#) for the latest version of the [Package/Carton Information](#).

Additional supplementary information with regard to packaging is listed below. Click on the relevant section to be transferred to the relevant website page.

- Package Information (include Outline Dimensions, Product Tape and Reel Specifications)
- The Operation Instruction of Packing Materials
- Carton information

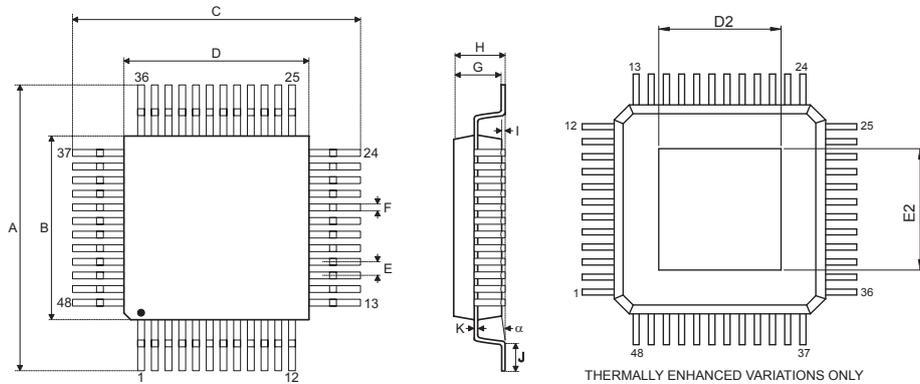
## SAW Type 32-pin QFN (4mm × 4mm × 0.75mm) Outline Dimensions



Symbol	Dimensions in inch		
	Min.	Nom.	Max.
A	0.028	0.030	0.031
A1	0.000	0.001	0.002
A3	0.008 REF		
b	0.006	0.008	0.010
D	0.157 BSC		
E	0.157 BSC		
e	0.016 BSC		
D2	0.100	—	0.108
E2	0.100	—	0.108
L	0.014	0.016	0.018
K	0.008	—	—

Symbol	Dimensions in mm		
	Min.	Nom.	Max.
A	0.70	0.75	0.80
A1	0.00	0.02	0.05
A3	0.203 REF		
b	0.15	0.20	0.25
D	4.00 BSC		
E	4.00 BSC		
e	0.40 BSC		
D2	2.55	—	2.75
E2	2.55	—	2.75
L	0.35	0.40	0.45
K	0.20	—	—

## 48-pin LQFP-EP (7mm × 7mm) Outline Dimensions



Symbol	Dimensions in inch		
	Min.	Nom.	Max.
A		0.354 BSC	
B		0.276 BSC	
C		0.354 BSC	
D		0.276 BSC	
E		0.020 BSC	
D2	0.170	—	0.211
E2	0.170	—	0.211
F	0.007	0.009	0.011
G	0.053	0.055	0.057
H	—	—	0.063
I	0.002	—	0.006
J	0.018	0.024	0.030
K	0.004	—	0.008
$\alpha$	0°	—	7°

Symbol	Dimensions in mm		
	Min.	Nom.	Max.
A		9.00 BSC	
B		7.00 BSC	
C		9.00 BSC	
D		7.00 BSC	
E		0.50 BSC	
D2	4.31	—	5.36
E2	4.31	—	5.36
F	0.17	0.22	0.27
G	1.35	1.40	1.45
H	—	—	1.60
I	0.05	—	0.15
J	0.45	0.60	0.75
K	0.09	—	0.20
$\alpha$	0°	—	7°

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