HT32F59741
Datasheet

Enhanced 24-bit A/D Arm® Cortex®-M0+ 32-Bit LCD Flash MCU
64 KB Flash and 8 KB SRAM with 1 MSPS 12-Bit ADC,
24-Bit Delta Sigma ADC, DIV, USART, UART, SPI, I^2C, GPTM,
PWM, BFTM, SCI, CRC, RTC, WDT, LCD and USB2.0 FS

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1 General Description

The Holtek HT32F59741 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 including advanced debug support.

The device operates at a frequency of up to 60 MHz with a Flash accelerator to obtain maximum efficiency. It provides up to 64 KB of embedded Flash memory for code/data storage and up to 8 KB of embedded SRAM memory for system operation and application program usage. A variety of peripherals, such as USB2.0 FS, Hardware Divider DIV, SPI, USART, UART, SCI, I^2C, GPTM, PWM, BFTM, CRC-16/32, RTC, WDT, ADC, LCD and 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.

A 24-bit Delta Sigma A/D converter which includes a programmable gain amplifier is also provided in the device for applications that interface differentially to analog signals.

The above features ensure that the device is suitable for use in a wide range of applications, especially in areas such as white goods application controllers, power monitors, alarm systems, consumer products, handheld equipment, data logging applications, motor controllers and so on.

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

- 64 KB on-chip Flash memory for instruction/data and options storage
- 8 KB on-chip SRAM
- Supports multiple boot modes

The Arm® Cortex®-M0+ processor accesses and debug accesses share the single external interface to external AHB peripherals. The processor accesses take priority over debug accesses. 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 32-bit memory map of the device, including code, SRAM, peripheral and other pre-defined regions.

Flash Memory Controller – FMC

- 32-bit word programming with In System Programming Interface (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 program/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
- External 32.768 kHz crystal oscillator
- Internal 8 MHz RC oscillator trimmed to ±2 % accuracy at 3.3 V operating voltage and 25 °C operating temperature
- Internal 32 kHz RC oscillator
- Integrated clock PLL and USB PLL
- Independent clock divider and gating bits for peripheral clock sources

The Clock Control Unit, CKCU, provides a range of oscillators and clock functions. These include a High Speed Internal RC oscillator (HSI), a High Speed External crystal oscillator (HSE), a Low Speed Internal RC oscillator (LSI), a Low Speed External crystal oscillator (LSE), a Phase Lock Loop (PLL), an HSE clock monitor, clock pre-scalers, clock multiplexers, APB clock divider and gating circuitry. The clocks of the AHB, APB and Cortex®-M0+ are derived from the system clock (CK_SYS) which can source from the HSI, HSE, LSI, LSE or system PLL. The Watchdog Timer and Real Time Clock (RTC) use either the LSI or LSE as their clock source.

Power Management Control Unit – PWRCU

- V_{DD} power supply: 1.65 V to 3.6 V
- Integrated 1.5 V LDO regulator for CPU core, peripherals and memories power supply
- V_{DD} power supply for RTC
- V_{DD} and V_{CORE} power domains
- Four power saving modes: Sleep, Deep-Sleep1, Deep-Sleep2 and Power-Down 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 these devices provides many types of power saving modes such as Sleep, Deep-Sleep1, Deep-Sleep2 and Power-Down 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.

External Interrupt/Event Controller – EXTI

- Up to 16 EXTI lines with configurable trigger sources and types
- 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 a wake-up event or interrupt requests independently. Each EXTI line can also be masked independently.

12-Bit Analog to Digital Converter – ADC

- 12-bit SAR ADC engine
- Up to 1 Msps conversion rate
- Up to 10 external analog input channels

A 12-bit multi-channel Analog to Digital Converter is integrated in the device. There are multiplexed channels, which include up to 10 external analog signal channels and 4 internal channels which can be measured. If the input voltage is required to remain within a specific threshold window, an Analog Watchdog function will monitor and detect these signals. An interrupt will then be generated to inform 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.

The internal voltage reference (V_{REF}) which can provide a stable reference voltage for the A/D Converter and Comparators is internally connected to the ADC_IN15 input channel. The precise voltage of the V_{REF} is individually measured for each part by Holtek during production test.

24-Bit Delta Sigma A/D Converter

- Internal Programmable Gain Amplifier
- Internal I^2C interface for external communications
- 5 Hz ~ 1.6 kHz ADC output data rate
- Internal temperature sensor for compensation

I/O Ports – GPIO

- Up to 53 GPIOs
- Port A, B, C, D are mapped as 16 external interrupts – EXTI
- Almost all I/O pins have configurable output driving current

There are up to 53 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 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.

General Purpose Timer – GPTM

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

The General Purpose Timer Module, 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. They can be used for a variety of purposes including general time measurement, input signal pulse width measurement, output waveform generation such as single pulse generation or PWM output generation. The GPTM supports an Encoder Interface using a decoder with two inputs.

Pulse Width Modulator – PWM

- 16-bit up / down auto-reload counter
- Up to 4 independent channels for each timer
- 16-bit programmable prescaler that allows division of the counter clock frequency by any factor between 1 and 65536
- Compare Match Output
- PWM waveform generation with Edge-aligned and Center-aligned Counting Modes
- Single Pulse Mode Output

The Pulse Width Modulator consists of one 16-bit up/down-counter, four 16-bit Compare Registers (CRs), one 16-bit Counter Reload Register (CRR) and several control / status registers. It can be used for a variety of purposes including general timer and output waveform generation such as single pulse generation or PWM output.

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 Module, BFTM, is a simple 32-bit up-counting counter designed to measure time intervals, generate one shots or generate repetitive interrupts. The BFTM can operate in two functional modes which are repetitive and one shot modes. In the repetitive mode, the counter will be 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
- Provide reset to the system
- Programmable watchdog timer window function
- Register write protection function

The Watchdog Timer is a hardware timing circuit that can be used to detect a system lock-up due to software trapped in a deadlock. It includes a 12-bit 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.

Real Time Clock – RTC

- 24-bit up-counter with a programmable prescaler
- Alarm function
- Interrupt and Wake-up event

The Real Time Clock, RTC, circuitry includes the APB interface, a 24-bit up-counter, a control register, a prescaler, a compare register and a status register. Most of the RTC circuits are located in the V_{DD} power domain except for the APB interface. The APB interface is located in the V_{CORE} power domain. Therefore, it is necessary to be isolated from the ISO signal that comes from the power control unit when the V_{CORE} power domain is powered off, i.e., when the devices enter the Power-Down mode. The RTC counter is used as a wakeup timer to generate a system resume or interrupt signal from the MCU power saving mode.

Inter-integrated Circuit – I²C

- 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 I²C is an internal circuit allowing communication with an external I²C interface which is an industry standard two line 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 I²C module provides three data transfer rates: 100 kHz in the Standard mode, 400 kHz in the Fast mode and 1 MHz in the Fast plus mode. The SCL period generation register is used to setup different kinds of duty cycle implementations for the SCL pulse.

The SDA line which is connected directly to the I²C bus is a bidirectional data line between the master and slave devices and is used for data transmission and reception. The I²C also has an arbitration detection and clock synchronization function to prevent the situations where more than one master attempts to transmit data to the I²C 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 a data byte, the streamed 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 Synchronous Asynchronous Receiver Transmitter – USART

- Supports both asynchronous and clocked synchronous serial communication modes
- Programming 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 data 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 a transmitter FIFO, (TX_FIFO) and receiver FIFO (RX_FIFO). The software can detect a USART error status by reading the USART Status & Interrupt Flag Register, USRSIFR. 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 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.

Smart Card Interface – SCI

- Supports ISO 7816-3 standard
- Character Transfer mode
- Single transmit buffer and single receive buffer
- 11-bit ETU (Elementary Time Unit) counter
- 9-bit guard time counter
- 24-bit general purpose waiting time counter
- Parity generation and check functions
- Automatic character retry on parity error detection in transmission and reception modes

The Smart Card Interface, SCI, is compatible with the ISO 7816-3 standard. This interface includes functions for Card Insertion/Removal detection, SCI data transfer control logic and data buffers,

internal Timer Counters and corresponding control logic circuits to perform the required Smart Card operations. The Smart Card interface acts as a Smart Card Reader to facilitate communication with the external Smart Card. The overall functions of the Smart Card interface are controlled by a series of registers including control and status registers together with several corresponding interrupts which are generated to get the attention of the microcontroller for SCI transfer status.

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

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.

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 needs a software triggered start signal by using the control register “START” bit. After 8 clock cycles, the divider calculate complete flag will be set to 1, and if the divisor register data is zero, the division by zero error flag will be set to 1.

Liquid Crystal Display Controller – LCD

- LCD Driver function with Static, 1/2, 1/3, 1/4, 1/6 and 1/8 duty
- LCD Driver function with Static, 1/2, 1/3 or 1/4 bias
- Supports R type bias type
- Clock source can be selected from the LSI (32 kHz), LSE (32.768 kHz) or a clock ratio of either the HSI or HSE

- Contains three embedded LCD bias reference resistor ladders
- Double buffered memory
- Software selectable charge pump voltage
- Programmable dead time between frames – up to 7/2 phase periods for type A waveforms and 7 phase periods for type B waveforms
- Software selectable waveform type: type A or type B waveform
- LCD frame interrupt
- Blink capability: Up to 1, 2, 3, 4, 8 or all pixels which can be programmed to blink

The LCD controller is a digital controller/driver for monochrome passive liquid crystal displays. It includes up to 8 common terminals and 29 segment terminals to drive 116 (4 commons × 29 segments) or 200 (8 commons × 25 segments) LCD picture elements (pixels). The exact number of terminals depends on the device package pin out. An integrated charge pump function can be enabled to provide the LCD glass with higher voltage than the system voltage.

Universal Serial Bus Device Controller – USB

- Complies with USB 2.0 Full-Speed (12 Mbps) specification
- Fully integrated USB full-speed transceiver
- 1 control endpoint (EP0) for control transfer
- 3 single-buffered endpoints for bulk and interrupt transfer
- 4 double-buffered endpoints for bulk, interrupt and isochronous transfer
- 1,024 bytes EP_SRAM used as the endpoint data buffers

The USB device controller is compliant with the USB 2.0 full-speed specification. There is one control endpoint known as Endpoint 0 and seven configurable endpoints. A 1024-byte SRAM is used as the endpoint buffers. Each endpoint buffer size is programmable using corresponding registers, thus providing maximum flexibility for various applications. The integrated USB full-speed transceiver helps to minimize overall system complexity and cost. The USB also contains suspend and resume features to meet low-power consumption requirement.

Debug Support

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

Package and Operation Temperature

- 64 / 80-pin LQFP packages
- Operation temperature range: -40 °C to 85 °C

3 Overview

Device Information

Table 1. Features and Peripheral List

Peripherals		HT32F59741
Main Flash (KB)		63
Option Bytes Flash (KB)		1
SRAM (KB)		8
Timers	GPTM	1
	PWM	2
	BFTM	2
	WDT	1
	RTC	1
Communication	USB	1
	SPI	2
	USART	1
	UART	2
	I^2C	2
	SCI (ISO7816-3)	1
Hardware Divider		1
LCD (COM × SEG)		8 × 25, 6 × 27, 4 × 29
CRC-16/32		1
EXTI		16
12-bit ADC Number of channels		1 10 Channels
24-bit ADC Number of channels		1 4 Channels
GPIO		Up to 53
CPU frequency		Up to 60 MHz
Operating voltage		1.65 V ~ 3.6 V
Operating temperature		-40 °C ~ 85 °C
Package		64 / 80-pin LQFP

Note: The functions listed here, except the 24-bit ADC, are compatible with the HT32F57341 device. Refer to the HT32F57341 user manual for detailed function description.

Block Diagram

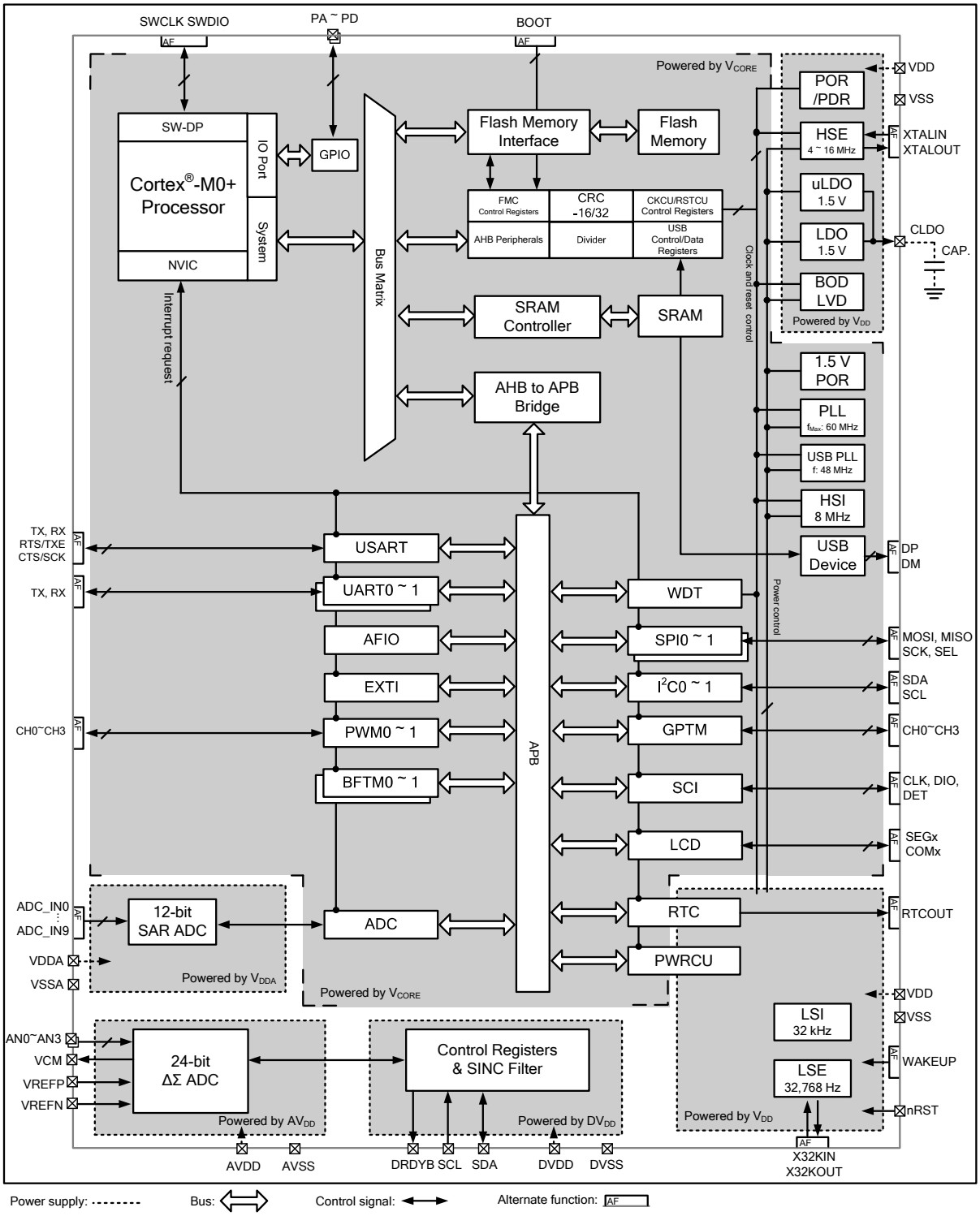


Figure 1. Block Diagram

Memory Map

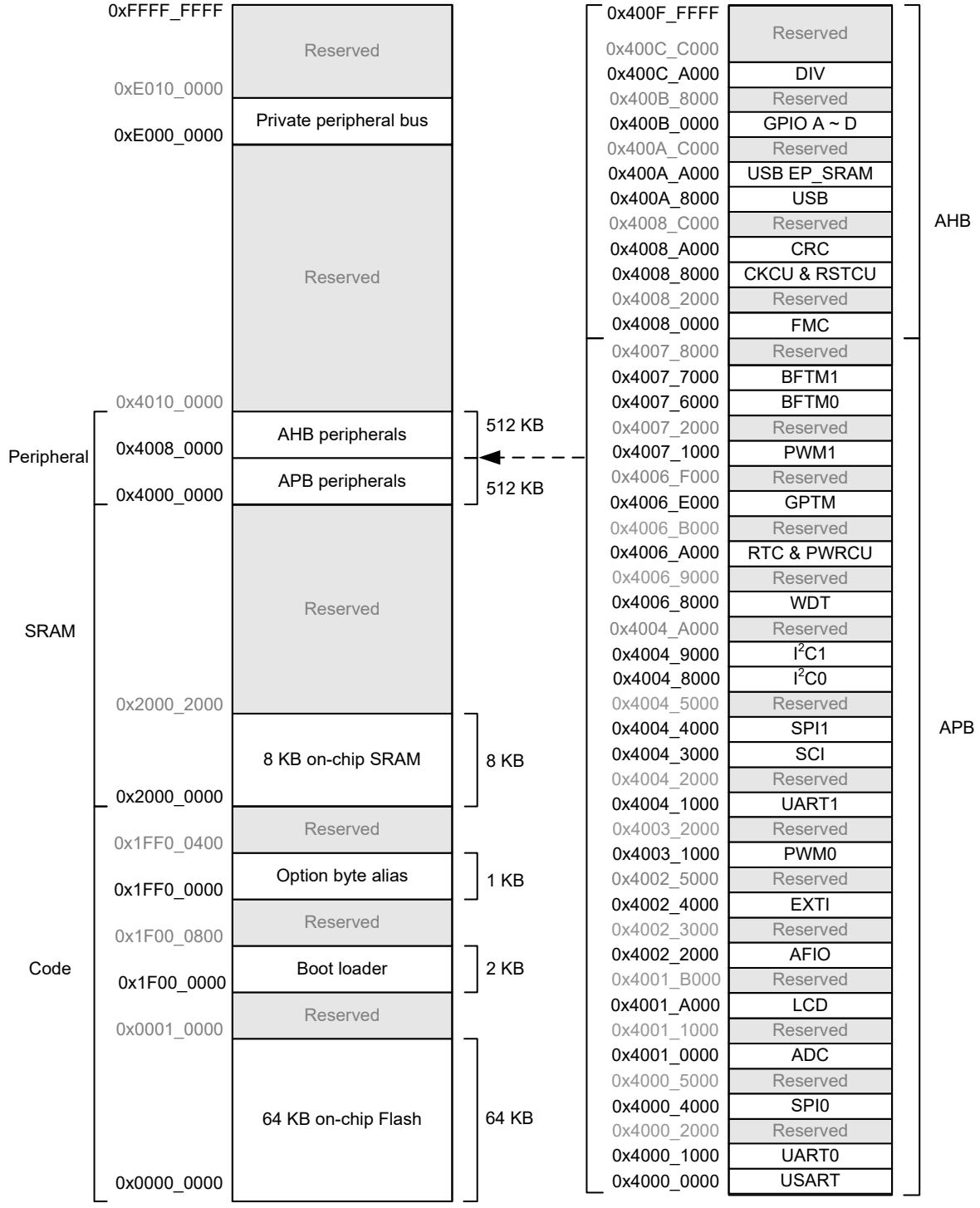


Figure 2. Memory Map

Table 2. Register Map

Start Address	End Address	Peripheral	Bus
0x4000_0000	0x4000_0FFF	USART	APB
0x4000_1000	0x4000_1FFF	UART0	
0x4000_2000	0x4000_3FFF	Reserved	
0x4000_4000	0x4000_4FFF	SPI0	
0x4000_5000	0x4000_FFFF	Reserved	
0x4001_0000	0x4001_0FFF	ADC	
0x4001_1000	0x4001_BFFF	Reserved	
0x4001_A000	0x4001_AFFF	LCD	
0x4001_B000	0x4002_1FFF	Reserved	
0x4002_2000	0x4002_2FFF	AFIO	
0x4002_3000	0x4002_3FFF	Reserved	
0x4002_4000	0x4002_4FFF	EXTI	
0x4002_5000	0x4003_0FFF	Reserved	
0x4003_1000	0x4003_1FFF	PWM0	
0x4003_2000	0x4004_0FFF	Reserved	
0x4004_1000	0x4004_1FFF	UART1	
0x4004_2000	0x4004_2FFF	Reserved	
0x4004_3000	0x4004_3FFF	SCI	
0x4004_4000	0x4004_4FFF	SPI1	
0x4004_5000	0x4004_7FFF	Reserved	
0x4004_8000	0x4004_8FFF	I^2C0	
0x4004_9000	0x4004_9FFF	I^2C1	
0x4004_A000	0x4006_7FFF	Reserved	
0x4006_8000	0x4006_8FFF	WDT	
0x4006_9000	0x4006_9FFF	Reserved	
0x4006_A000	0x4006_AFFF	RTC & PWRCU	
0x4006_B000	0x4006_DFFF	Reserved	
0x4006_E000	0x4006_EFFF	GPTM	
0x4006_F000	0x4007_0FFF	Reserved	
0x4007_1000	0x4007_1FFF	PWM1	
0x4007_2000	0x4007_5FFF	Reserved	
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	0x400A_7FFF	Reserved	
0x400A_8000	0x400A_9FFF	USB	
0x400A_A000	0x400A_BFFF	USB EP_SRAM	
0x400A_C000	0x400A_FFFF	Reserved	
0x400B_0000	0x400B_1FFF	GPIOA	
0x400B_2000	0x400B_3FFF	GPIOB	
0x400B_4000	0x400B_5FFF	GPIOC	
0x400B_6000	0x400B_7FFF	GPIOD	
0x400B_8000	0x400C_9FFF	Reserved	
0x400C_A000	0x400C_BFFF	DIV	
0x400C_C000	0x400F_FFFF	Reserved	

Clock Structure

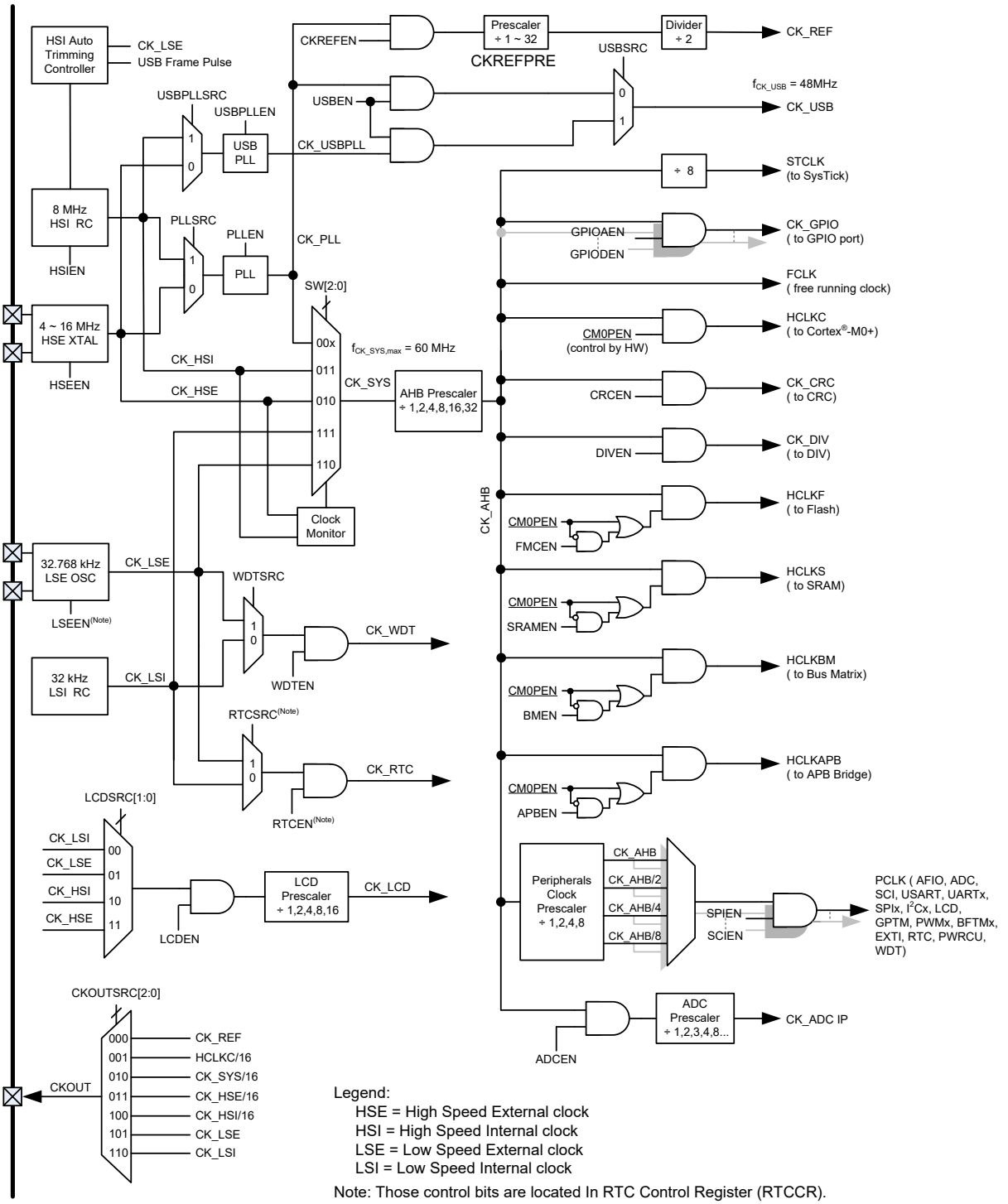


Figure 3. Clock Structure

4 24-Bit A/D Converter

The device contains a high accuracy multi-channel 24-bit Delta Sigma type analog-to-digital converter which can directly interface to external analog signals, such as that from sensors or other control signals and convert these signals directly into a 24-bit digital value. In addition to the core analog to digital converter circuitry, the A/D converter module also includes an internal Programmable Gain Amplifier PGA. The PGA gain control, ADC gain control and ADC reference gain control determine the overall amplification gain for ADC input signal, giving users a flexible way of setting up an overall gain to achieve an optimum amplification of the input signal for their specific applications. The converter has a total of four inputs allowing the formation of two differential input channels. The converter output is filtered via a SINC filter and the result stored as a 24-bit value in three data registers. An internal voltage regulator and reference sources are also included as well as a temperature sensor for A/D converter compensation due to temperature effects.

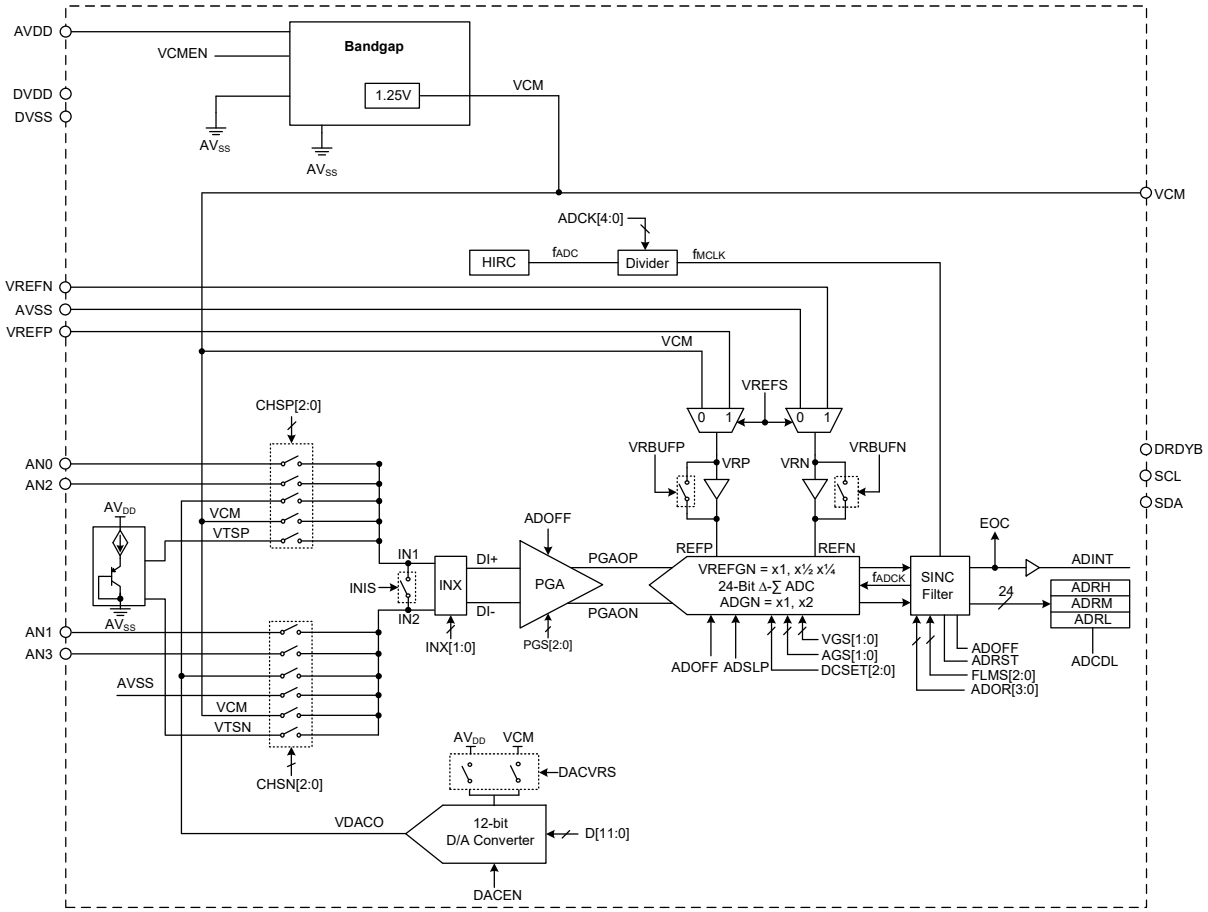


Figure 4. 24-bit A/D Converter Block Diagram

24-Bit A/D Converter Registers

The A/D converter is setup and operated using a series of internal registers. Device commands and data are written to and read from the 24-bit A/D converter module using its internal I²C bus. This list provides a summary of all internal registers about the module, their detailed operation is described under their relevant section in the functional description.

Register Initial Values

The following table shows the internal value of the individual register after a power on reset.

Register	Power On Reset Value
PWRC	0000 0000
PGAC0	-000 0000
PGAC1	-000 000-
PGACS	--00 0000
ADRL	xxxx xxxx
ADRM	xxxx xxxx
ADRH	xxxx xxxx
ADCR0	0010 0000
ADCR1	0000 000-
ADCS	---0 0000
ADCTE	1110 0100
DAH	0000 0000
DAL	---- 0000
DACC	00-- ----
SIMC0	0--- 00--
SIMTOC	0000 0000
HIRCC	---- -001

Table Legend

Item	Description
*	Warm reset
-	Not implemented
u	Unchanged
x	Unknown

Address	Register Name	Bit							
		7	6	5	4	3	2	1	0
00H	PWRC	VCMEN	D6	D5	D4	D3	D2	D1	D0
01H	PGAC0	—	VGS1	VGS0	AGS1	AGS0	PGS2	PGS1	PGS0
02H	PGAC1	—	INIS	INX1	INX0	DCSET2	DCSET1	DCSET0	—
03H	PGACS	—	—	CHSN2	CHSN1	CHSN0	CHSP2	CHSP1	CHSP0
04H	ADRL	D7	D6	D5	D4	D3	D2	D1	D0
05H	ADRM	D15	D14	D13	D12	D11	D10	D9	D8
06H	ADRH	D23	D22	D21	D20	D20	D19	D18	D17

Address	Register Name	Bit							
		7	6	5	4	3	2	1	0
07H	ADCR0	ADRST	ADSLP	ADOFF	ADOR3	ADOR2	ADOR1	ADOR0	VREFS
08H	ADCR1	FLMS2	FLMS1	FLMS0	VRBUFN	VRBUFP	ADCDL	EOC	—
09H	ADCS	—	—	—	ADCK4	ADCK3	ADCK2	ADCK1	ADCK0
0AH	ADCTE	D7	D6	D5	D4	D3	D2	D1	D0
0BH	DAH	D11	D10	D9	D8	D7	D6	D5	D4
0CH	DAL	—	—	—	—	D3	D2	D1	D0
0DH	DACC	DACEN	DACVRS	—	—	—	—	—	—
0EH	SIMC0	SIMS	—	—	—	SIMDEB1	SIMDEB0	—	—
10H	SIMTOC	SIMTOEN	SIMTOF	SIMTOS5	SIMTOS4	SIMTOS3	SIMTOS2	SIMTOS1	SIMTOS0
11H	HIRCC	—	—	—	—	—	HIRCO	HIRCF	HIRCEN
12H	Reserved, cannot be changed								

Internal Power Supply

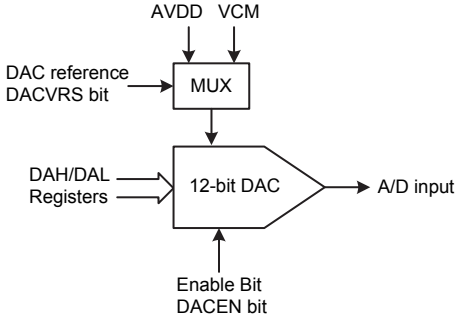
This A/D converter module contains the VCM for the regulated power supply. The VCM can be used as the reference voltage for ADC module. The VCM function is controlled by the VCMEN bit and can be powered off to reduce the power consumption.

Reference Voltages

An internal voltage reference source, known as the VCM, is used as a converter reference. The VCM is sourced from a bandgap reference generator thus providing a temperature stable reference and has a output voltage level fixed at 1.25V. The VCM function is controlled by the VCMEN bit and can be switched off to reduce the power consumption.

The converter reference voltage range is supplied on two external reference pins, VREFP and VREFN. These offer a full reference voltage range of AV_{SS} to AV_{DD}. This externally supplied reference voltage can be attenuated by 0.5 or 0.25 using the VREFGN bits in the PGAC0 register.

An internal DAC is also provided as an additional reference voltage source. The DAC has two reference voltages which define the maximum value, supplied by either AVDD or VCM. The DAC 12-bit value is setup using two data registers, DAL and DAH and selected using the DACVRS bit in the DACC register. The overall enable bit for the DAC is the DACEN bit in the DACC register.



• **DAH Register − 0BH**

Bit	7	6	5	4	3	2	1	0
Name	D11	D10	D9	D8	D7	D6	D5	D4
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
POR	0	0	0	0	0	0	0	0

Bit 7~0 **D11~D4**: DAC output control code

• **DAL Register − 0CH**

Bit	7	6	5	4	3	2	1	0
Name	—	—	—	—	D3	D2	D1	D0
R/W	—	—	—	—	R/W	R/W	R/W	R/W
POR	—	—	—	—	0	0	0	0

Bit 7~4 Unimplemented, read as "0"

Bit 3~0 **D3~D0**: DAC output control code

Note: writing to this register only writes to a shadow buffer. Not until data is written to the DAH register will the actual data be written into the DAL register.

• **DACC Register − 0DH**

Bit	7	6	5	4	3	2	1	0
Name	DACEN	DACVRS	—	—	—	—	—	—
R/W	R/W	R/W	—	—	—	—	—	—
POR	0	0	—	—	—	—	—	—

Bit 7 **DACEN**: DAC enable or disable control bit
0: Disable
1: Enable

Bit 6 **DACVRS**: DAC reference voltage selection
0: DAC reference voltage sourced from AVDD
1: DAC reference voltage sourced from VCM

Bit 5~0 Unimplemented, read as "0"

Power and Reference Control

The following table shows the overall control of the power and voltage sources.

Registers		Output voltage	
ADOFF	VCMEN	Bandgap	VCM
1	0	Off	Disable
1	1	On	Enable
0	0	On	Disable
0	1	On	Enable

Power Control Table

Power Control Registers

• **PWRC Register − 00H**

Bit	7	6	5	4	3	2	1	0
Name	VCMEN	D6	D5	D4	D3	D2	D1	D0
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
POR	0	0	0	0	0	0	0	0

Bit 7 **VCMEN**: VCM function enable control
0: Disable
1: Enable
If the VCM is disabled, there will be no power consumption and VCM output pin is floating.

Bit 6~0 **D6~D0**: Performance optimizing bits
010_1000B: when ADCR1[FLMS2~0] = 000B ($f_{ADCK} = f_{MCLK}/30$)
011_1100B: when ADCR1[FLMS2~0] = 010B ($f_{ADCK} = f_{MCLK}/12$)
Others: reserved

Oscillator

There is an fully internal oscillator which provides 4.9152MHz clock frequency in the A/D converter module.

Oscillator Control Register

There is a control register for the internal oscillator. Note that a full 16 clock cycle time is required for the oscillator to stabilise.

• **HIRCC Register − 11H**

Bit	7	6	5	4	3	2	1	0
Name	—	—	—	—	—	HIRCO	HIRCF	HIRCEN
R/W	—	—	—	—	—	R/W	R	R/W
POR	—	—	—	—	—	0	0	1

Bit 7~3 Unimplemented, read as "0"

Bit 2 **HIRCO**: HIRC clock output
This bit must be reserved at "0"

Bit 1 **HIRCF**: HIRC oscillator stable flag
0: Unstable
1: Stable
The HIRC stable time will spend 16 clocks when HIRCEN is enabled.

Bit 0 **HIRCEN**: HIRC oscillator enable control
0: Disable
1: Enable

Input Signal Gain Control Amplifier – PGA

An internal programmable gain amplifier is provided to amplify the differential input signal before being converted. All input signals to the analog to digital converter must pass through the PGA. This pre-processing of the input signal enables an optimal signal range to be setup to obtain a converted value with optimal resolution.

PGA Registers

The PGA is controlled using a series of registers to setup the gain value and also to select the input source.

- **PGAC0 Register − 01H**

Bit	7	6	5	4	3	2	1	0
Name	—	VGS1	VGS0	AGS1	AGS0	PGS2	PGS1	PGS0
R/W	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W
POR	—	0	0	0	0	0	0	0

Bit 7 Unimplemented, read as "0"

Bit 6~5 **VGS1~VGS0**: REFP/REFN differential reference voltage gain selection
00: VREFGN = 1
01: VREFGN = 1/2
10: VREFGN = 1/4
11: Reserved

Bit 4~3 **AGS1~AGS0**: ADC converter PGAOP/PGAON differential input signal gain selection
00: ADGN = 1
01: ADGN = 2 (for Gain = 128 = PGAGN × ADGN = 64 × 2)
10: Reserved
11: Reserved

Bit 2~0 **PGS2~PGS0**: PGA DI+/DI- differential channel input gain selection
000: PGAGN = 1
001: PGAGN = 2
010: PGAGN = 4
011: PGAGN = 8
100: PGAGN = 16
101: PGAGN = 32
110: PGAGN = 64
111: Reserved

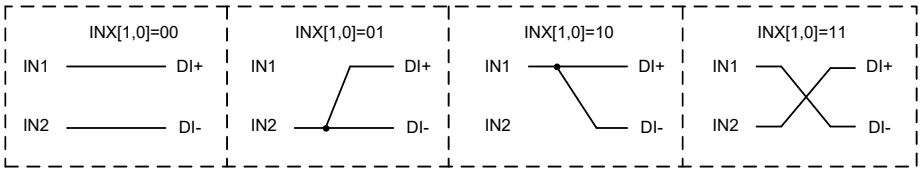
- **PGAC1 Register − 02H**

Bit	7	6	5	4	3	2	1	0
Name	—	INIS	INX1	INX0	DCSET2	DCSET1	DCSET0	—
R/W	—	R/W	R/W	R/W	R/W	R/W	R/W	—
POR	—	0	0	0	0	0	0	—

Bit 7 Unimplemented, read as "0"

Bit 6 **INIS**: Selected input terminals IN1/IN2 internal connection
0: Not connected
1: Connected

Bit 5~4 **INX1, INX0**: The selected input ends ,IN1/IN2 and the PGA differential input ends, DI+/DI- connection control bits



Bit 3~1 **DCSET2~DCSET0**: Differential input signal PGAOP/PGAON offset selection

000: DCSET = +0V
001: DCSET = +0.25 × ΔVR_I
010: DCSET = +0.5 × ΔVR_I
011: DCSET = +0.75 × ΔVR_I
100: DCSET = +0V
101: DCSET = -0.25 × ΔVR_I
110: DCSET = -0.5 × ΔVR_I
111: DCSET = -0.75 × ΔVR_I

The voltage, ΔVR_I, is the differential reference voltage which is amplified by the specific gain selection based on the selected inputs.

Bit 0 Unimplemented, read as "0"

PGA Input Channel Selection

In addition to the external analog input to be measured by the converter, there are several other internal analog voltage lines which can be connected to the converter. These come from a range of sources such as the temperature sensor and are normally used for calibration purposes.

- **PGACS Register − 03H**

Bit	7	6	5	4	3	2	1	0
Name	—	—	CHSN2	CHSN1	CHSN0	CHSP2	CHSP1	CHSP0
R/W	—	—	R/W	R/W	R/W	R/W	R/W	R/W
POR	—	—	0	0	0	0	0	0

Bit 7~6 Unimplemented, read as "0"

Bit 5~3 **CHSN2~CHSN0**: PGA negative input end IN2 selection

000: AN1
001: AN3
010: Reserved
011: Reserved
100: VDACO
101: AVSS
110: VCM
111: VTSN – Temperature sensor negative output

These bits are used to select the negative input, IN2. If the IN2 input is selected as a single end input, the VCM voltage must be selected as the positive input on IN1 for single end input applications. It is recommended that when the VTSN signal is selected as the negative input, the VTSP signal should be selected as the positive input for proper operations.

Bit 2~0 **CHSP2~CHSP0**: Positive input end IN1selection
000: AN0
001: AN2
010: Reserved
011: Reserved
100: VDACO
101: Reserved
110: VCM
111: VTSP – Temperature sensor positive output

These bits are used to select the positive input, IN1. If the IN1 input is selected as a single end input, the VCM voltage must be selected as the negative input on IN2 for single end input applications. It is recommended that when the VTSP signal is selected as the positive input, the VTSN signal should be selected as the negative input for proper operations.

Analog to Digital Converter Operation

The analog to digital converter received a differential analog signal from the PGA output and converts in using a Delta Sigma converter into a 24-bit digital value. The overall operation of the converter is controlled by a series of control registers.

- **ADCR0 Register − 07H**

Bit	7	6	5	4	3	2	1	0
Name	ADRST	ADSLP	ADOFF	ADOR3	ADOR2	ADOR1	ADOR0	VREFS
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
POR	0	0	1	0	0	0	0	0

Bit 7 **ADRST**: A/D converter software reset enable control
0: Disable
1: Enable

This bit is used to reset the A/D converter internal digital SINC filter. This bit is set low for A/D normal operations. However, if set high, the internal digital SINC filter will be reset and the current A/D converted data will be aborted. A new A/D data conversion process will not be initiated until this bit is set low again.

Bit 6 **ADSLP**: A/D converter sleep mode enable control
0: Normal mode
1: Sleep mode

This bit is used to determine whether the A/D converter enters the sleep mode or not when the A/D converter is powered on by setting the ADOFF bit low. When the A/D converter is powered on and the ADSLP bit is low, the A/D converter will operate normally. However, the A/D converter will enter the sleep mode if the ADSLP bit is set high as the A/D converter has been powered on. The whole A/D converter circuit will be switched off except the PGA and internal Bandgap circuit to reduce the power consumption and VCM start-up stable time.

Bit 5 **ADOFF**: A/D converter module power on/off control
0: Power on
1: Power off
This bit controls the power of the A/D converter module. This bit should be cleared to zero to enable the A/D converter. If the bit is set high then the A/D converter will be switched off reducing the device power consumption. As the A/D converter will consume a limited amount of power, even when not executing a conversion, this may be an important consideration in power sensitive battery powered applications.
Setting the ADOFF bit high will power down the A/D converter module regardless of the ADSLP and ADRST bit settings.

Bit 4~1 **ADOR3~ADOR0**: A/D conversion oversampling rate selection
0000: Oversampling rate OSR = 32768
0001: Oversampling rate OSR = 16384
0010: Oversampling rate OSR = 8192
0011: Oversampling rate OSR = 4096
0100: Oversampling rate OSR = 2048
0101: Oversampling rate OSR = 1024
0110: Oversampling rate OSR = 512
0111: Oversampling rate OSR = 256
1000: Oversampling rate OSR = 128
Others: Reserved

Bit 0 **VREFS**: A/D converter reference voltage pair selection
0: Internal reference voltage pair – V_{CM} & AV_{SS}
1: External reference voltage pair – V_{REFP} & V_{REFN}

- **ADCR1 Register – 08H**

Bit	7	6	5	4	3	2	1	0
Name	FLMS2	FLMS1	FLMS0	VRBUFN	VRBUFP	ADCDL	EOC	—
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	—
POR	0	0	0	0	0	0	0	—

Bit 7~5 **FLMS2~FLMS0**: A/D converter clock divided ratio selection
000: $f_{ADCK} = f_{MCLK}/30$, N = 30
010: $f_{ADCK} = f_{MCLK}/12$, N = 12
Others: Reserved

Bit 4 **VRBUFN**: A/D converter negative reference voltage input (VRN) buffer control
0: Disable input buffer and enable bypass function
1: Enable input buffer and disable bypass function

Bit 3 **VRBUFP**: A/D converter positive reference voltage input (VRP) buffer control
0: Disable input buffer and enable bypass function
1: Enable input buffer and disable bypass function

Bit 2 **ADCDL**: A/D converted data latch function enable control
0: A/D converted data updated
1: A/D converted data not updated
If the A/D converted data latch function is enabled, the latest converted data value will be latched and not be updated by any subsequent converted results until this function is disabled. Although the converted data is latched into the data registers,

the A/D converter circuits remain operational and EOC flag will not change state. It is recommended that this bit should be set high before reading the converted data in the ADRL, ADRM and ADRH registers. After the converted data has been read out, the bit can then be cleared to zero to disable the A/D converter data latch function and allow further conversion values to be stored. In this way, the possibility of obtaining undesired data during A/D converter conversions can be prevented.

Bit 1 **EOC**: End of A/D conversion flag
0: A/D conversion in progress
1: A/D conversion ended
This flag will be automatically set high by the hardware when a conversion process has completed but must be cleared by the application software.

Bit 0 Unimplemented, read as "0"

A/D Data Rate Definition

The Delta Sigma ADC data rate can be calculated by the equation list below.

Data Rate = f_{ADCK} / OSR
= (f_{MCLK}/N) / OSR
= f_{MCLK} / (N × OSR)

f_{ADCK}: f_{MCLK}/N

f_{MCLK}: f_{ADC} or f_{ADC}/2/(ADCK + 1) using the ADCK bit field.

N: 30 or 12 determined by the FLMS bit field.

OSR: Oversampling rate determined by the ADOR field.

For example; if a data rate of 10 Hz is desired. An f_{MCLK} clock source with a frequency of 4.9152 MHz ADC can be selected. Then set the FLMS field to "000" to obtain an "N" equal to 30. Finally, set the ADOR field to "0001" to select an oversampling rate equal to 16384. Therefore, the Data Rate = 4.9152 MHz / (30 × 16384) = 10 Hz.

Note that the A/D converter has a notch rejection function for an A/C power supply with a frequency of 50 Hz or 60 Hz when the data rate is equal to 10 Hz.

A/D Converter Clock Source

The clock source for the A/D converter should be typically fixed at a value of 4.9152 MHz, which originates from the ADC clock f_{ADC}. This can be chosen to be either f_{ADC} or a subdivision of f_{ADC}. The division ratio value is determined by the ADCK4 ~ ADCK0 bits in the ADCS register to obtain a 4.9152 MHz clock source for the ADC.

Internal OSC = 4.9152 MHz, f_{ADCK} = f_{MCLK}/30.

Data Rate (Hz)	ADCK4~0	ADOR3~0	FLMS2~0
10	11111	0001	000

Internal OSC = 4.9152 MHz, f_{ADCK} = f_{MCLK}/12.

Data Rate (Hz)	ADCK4~0	ADOR3~0	FLMS2~0
25	11111	0001	010

• **ADCS Register − 09H**

Bit	7	6	5	4	3	2	1	0
Name	—	—	—	ADCK4	ADCK3	ADCK2	ADCK1	ADCK0
R/W	—	—	—	R/W	R/W	R/W	R/W	R/W
POR	—	—	—	0	0	0	0	0

Bit 7~5 Unimplemented, read as "0"

Bit 4~0 **ADCK4~ADCK0**: A/D converter clock source f_{MCLK} divided ratio selection
00000~11110: $f_{MCLK} = f_{ADC}/2/(ADCK[4:0] + 1)$
11111: $f_{MCLK} = f_{ADC}$

• **ADCTE Register − 0AH**

Bit	7	6	5	4	3	2	1	0
Name	D7	D6	D5	D4	D3	D2	D1	D0
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
POR	1	1	1	0	0	1	0	0

Bit 7~0 Reserved bits, should be fixed as 1110_0111B.

A/D Operating Modes

The A/D Converter has four operating modes, which are the Normal mode, Power down mode, Sleep mode and Reset mode. These modes are controlled by a combination of the ADOFF, ADSLP and ADRST bits in the ADCR0 register as shown in the accompanying table. The ADOFF controls the overall on/off condition and if high will power down the A/D converter to reduce power. When the ADOFF bit is low, the converter will be powered on and the ADSLP bit will determine if the converter is in the normal operating mode or in the sleep mode.

ADOFF	ADSLP	ADRST	Operating Mode	Description
1	x	x	Power down mode	Bandgap off, PGA off, ADC off, Temperature sensor off, VRN/VRP buffer off, SINC filter off
0	1	x	Sleep mode	Bandgap on, PGA on, ADC off, Temperature sensor off, VRN/VRP buffer off, SINC filter on
0	0	0	Normal mode	Bandgap on, PGA on, ADC on, Temperature sensor on/off, VRN/VRP buffer on/off, SINC filter on
0	0	1	Reset mode	Bandgap on, PGA on, ADC on, Temperature sensor on/off, VRN/VRP buffer on/off, SINC filter Reset

"x" unknown

A/D Operating Mode Summary

Notes: 1. The VCM generator can be switched on or off by configuring the VCMEN bit.
2. The Temperature sensor can be switched on or off by configuring the CHSN[2:0] or CHSP[2:0] bits
3. The VRN buffer can be switched on or off by configuring the VRBUFN bit while the VRP buffer can be switched on or off by configuring the VRBUFP bit

A/D Conversion Process

To enable the A/D Converter, the first step is to disable the ADC power down and sleep mode by clearing the ADOFF and ADSLP bits to make sure the A/D Converter is powered up. The ADRST bit in the ADCR0 register is used to start and reset the A/D converter after power on. To set ADRST bit from low to high and then low again, an analog to digital converted data in SINC filter will be initiated. After this setup is complete, the A/D Converter is ready for operation. These three bits are used to control the overall start operation of the internal analog to digital converter.

The EOC bit in the ADCR1 register is used to indicate when the analog to digital conversion process is complete. This bit will be automatically set to "1" by the Hardware after a conversion cycle has ended. The ADC converted data will be updated continuously by new converted data. If the ADC converted data latch function is enabled, the latest converted data will be latched and the following new converted data will be discarded until this data latch function is disabled.

The differential reference voltage supply to the A/D Converter can be supplied from either the internal power supply, VCM and AVSS, or from an external reference source supplied on pins VREFP and VREFN. The desired selection is made using the VREFS bit in the ADCR0 register.

Summary of A/D conversion steps

- Step 1
  Enable the power VCM for PGA and ADC.
- Step 2
  Select the PGA, ADC, reference voltage gains by PGAC0 register
- Step 3
  Select the PGA settings for input connection, VCM voltage level and buffer option by PGAC1 register
- Step 4
  Select the required A/D conversion clock source 4.9152 MHz by correctly programming bits ADCK4 ~ ADCK0 in the ADCS register.
- Step 5
  Select output data rate by cofiguring the ADOR[2:0] bits in the ADCR0 register and FLMS[2:0] bits in the ADCR1 register.
- Step 6
  Select which channel is to be connected to the internal PGA by correctly programming the CHSP2 ~ CHSP0 and CHSN2 ~ CHSN0 bits which are also contained in the PGACS register.
- Step 7
  Release the power down mode and sleep mode by clearing the ADOFF and ADSLP bits in ADCR0 register.
- Step 8
  Reset the A/D by setting the ADRST to high in the ADCR0 register and clearing this bit to zero to release reset status.
- Step 9
  To check when the analog to digital conversion process is complete, the EOC bit in the ADCR1 register can be polled. The conversion process is complete when this bit goes high. When this occurs the A/D data registers ADRL, ADRM and ADRH can then be read to obtain the conversion value.

A/D Transfer Function

As the converted value is 24-bits its full-scale converted digitised value has a decimal value of 8388607 to -8388608. The converted data format is formed by a two's complement binary value. The MSB of the converted data is the signed bit. Since the full-scale analog input value is equal to the amplified value of the VCM or differential reference input voltage, ΔVR_I, selected by the VREFS bit in ADCR0 register, this gives a single bit analog input value of ΔVR_I divided by 8388608.

$$1\ LSB = \Delta VR\_I / 8388608$$

The A/D Converter input voltage value can be calculated using the following equation:

$$\Delta SI\_I = (PGAGN \times ADGN \times \Delta DI\pm) + DCSET$$

$$\Delta VR\_I = VREFGN \times \Delta VR \pm$$

$$ADC\_Conversion\_Data = (\Delta SI\_I / \Delta VR\_I) \times K$$

Where K is equal to 2^{23}.

Notes: 1. The PGAGN, ADGN, VREFGN values are determined by the PGS, AGS, VGS control bits.

2. ΔSI_I is the differential input signal after amplification and offset adjustment

3. PGAGN: Programmable Gain Amplifier gain

4. ADGN: A/D Converter gain

5. VREFGN: Reference voltage gain

6. ΔDI±: Differential input signal derived from external channels or internal signals

7. DCSET: Offset voltage

8. ΔVR±: Differential reference voltage

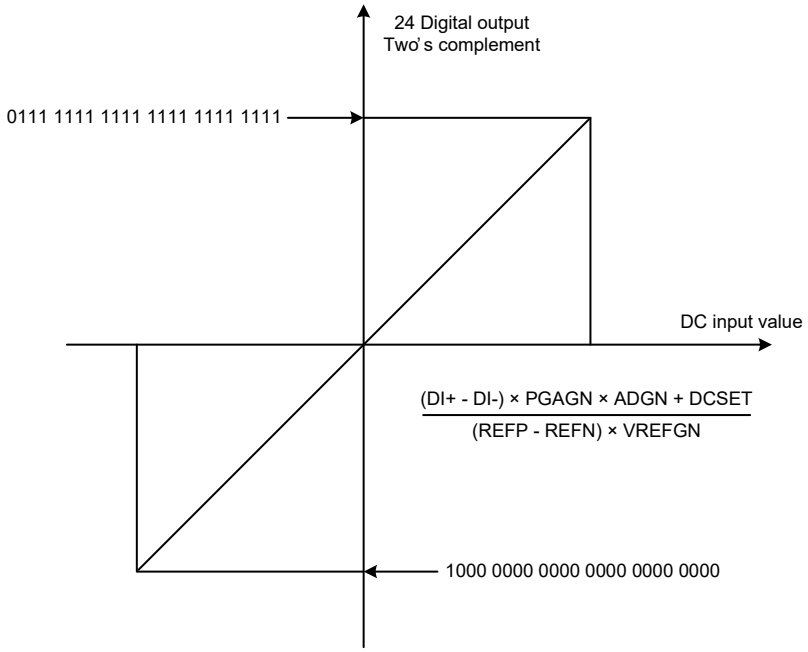
9. ΔVR_I: Differential reference input voltage after amplification

Due to the digital system design of the converter, the maximum A/D converted value is 8388607 and the minimum value is -8388608, therefore the centre value is 0. The ADC_Conversion_Data equation illustrates this range of converted data variation.

Converted Data 2's compliment Hex value	Decimal Value
0x7FFFFF	8388607
0x800000	-8388608

A/D Conversion Data Range

The following diagram shows the relationship between the DC input value and the ADC converted data which is presented in Two's Complement format.



A/D Converted Data

The A/D converter data is stored in three individual registers, ADRL, ADRM and ADRH. The converted data is related to the input voltage and the PGA selection setup and is generated in a two's complement binary code formal. The length of this output code is 24 bits and the MSB is a signed bit. When the MSB is "0", this indicates that the input is "positive", while if the MSB is "1", this indicates that the input is "negative". The maximum value is 8388607 and the minimum value is -8388608. If the input signal exceeds the maximum value, the converted data is limited to 8388607, and if the input signal is less than the minimum value, the converted data is limited to -8388608.

- **ADRL Register − 04H**

Bit	7	6	5	4	3	2	1	0
Name	D7	D6	D5	D4	D3	D2	D1	D0
R/W	R	R	R	R	R	R	R	R
POR	x	x	x	x	x	x	x	x

Bit 7~0 A/D conversion data register bit 7 ~ bit 0

- **ADRM Register − 05H**

Bit	7	6	5	4	3	2	1	0
Name	D15	D14	D13	D12	D11	D10	D9	D8
R/W	R	R	R	R	R	R	R	R
POR	x	x	x	x	x	x	x	x

Bit 7~0 A/D conversion data register bit 15 ~ bit 8

• **ADRH Register − 06H**

Bit	7	6	5	4	3	2	1	0
Name	D23	D22	D21	D20	D19	D18	D17	D16
R/W	R	R	R	R	R	R	R	R
POR	x	x	x	x	x	x	x	x

Bit 7~0 A/D conversion data register bit 23 ~ bit 16

Converting the Digital Value to a Voltage

The analog voltage value can be recovered using the following equations:

If the MSB = 0 for positive value converted data:

$$\text{Input Voltage} = \frac{(\text{Converted\_data}) \times \text{LSB} - \text{DCSET}}{\text{PGA} \times \text{ADGN}}$$

If the MSB = 1for negative converted data:

$$\text{Input voltage} = \frac{(\text{Two's\_complement\_of\_Converted\_data}) \times \text{LSB} - \text{DCSET}}{\text{PGA} \times \text{ADGN}}$$

Note: Two's complement = One's complement + 1

Temperature Sensor

The A/D converter module includes a fully internal temperature sensor to allow for compensation due to temperature effects. By selecting the PGA input channels to VTSP and VTSN signals, the A/D Converter can obtain temperature information and then use the result to compensate the A/D converted data to minimise the effects of temperature.

Effective Number of Bits – ENOB

Although the analog to digital converter is a 24-bit type various factors such as the PGA gain and the data rate affect the actual number of effective number of converted bits.

Programming Considerations

During microcontroller operations where the A/D converter is not being used, the A/D internal circuitry can be switched off to reduce power consumption, by setting bit ADOFF high in the ADCR0 register. When this happens, the internal A/D converter circuits will not consume power irrespective of what analog voltage is applied to their input lines.

When writing to the DAC registers, DAH and DAL, note that this must be carried out in a special sequence. This is because when writing to the DAL register, the data is only written into a shadow buffer register. Only when data is written to the DAH register will data in the shadow buffer be transferred to the DAL register. Therefore when writing data to the DAC registers first write data to the DAL register and then to the DAH register.

External Interface Communication

The A/D converter module communicates with external hardware using its internal I^2C interface. Originally developed by Philips, the I^2C interface is a two line low speed serial interface for synchronous serial data transfer. With the advantage of only two lines for communication, a

relatively simple communication protocol and the ability to accommodate multiple devices on the same bus has made it an extremely popular interface type for many applications.

I²C Interface Operation

The I²C serial interface is a two line interface, a serial data line, SDA, and serial clock line, SCL. As many devices may be connected together on the same bus, their outputs are both open drain types. For this reason it is necessary that external pull-high resistors are connected to these outputs. Note that no chip select line exists, as each device on the I²C bus is identified by a unique address which will be transmitted and received on the I²C bus. When two devices communicate with each other on the bidirectional I²C bus, one is known as the master device and one as the slave device. Both master and slave can transmit and receive data, however, it is the master device that has overall control of the bus, and it is only the master that will drive the SCL clock line. This A/D converter module only operates in the slave mode, and will therefore only operate in response to the master. There are two methods for this A/D converter module to transfer data on the I²C bus, the slave transmit mode and the slave receive mode.

Several registers control the overall operation of the I²C bus interface.

I²C Address and Register Write/Read

I²C Address Selection

As this A/D converter module only operates as a slave, and as it may be connected to a common I²C bus along with other I²C devices, it will require a specific address for it to be communicated to by the external master. The module I²C address is fixed at 0xD0.

• SIMC0 Register − 0EH

Bit	7	6	5	4	3	2	1	0
Name	SIMS	—	—	—	SIMDEB1	SIMDEB0	—	—
R/W	R/W	—	—	—	R/W	R/W	—	—
POR	0	—	—	—	0	0	—	—

Bit 7 **SIMS**
0: Normal operation
1: Results in unpredictable behavior
This bit must be kept at a zero value for normal operation

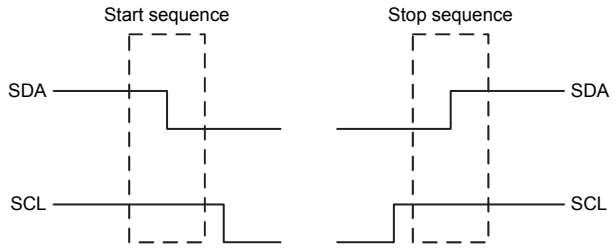
Bit 6~4 Unimplemented, read as “0”

Bit 3~2 **SIMDEB1~SIMDEB0**: I²C debounce time selection
00: No debounce
01: 2 ADC clock debounce
10: 4 ADC clock debounce
11: 4 ADC clock debounce

Bit 1~0 Unimplemented, read as “0”

Start and Stop Operations

Normally the SDA line can only change when the SCL line is low. There are two exceptions however and that is for the Start and Stop operations, where the SCL line will be forced high by the master and the SDA line will change sate. As the diagram shows when the SCL line is high, a high to low SDA line transition indicates a start operation and a low to high SDA line transition indicates a stop operation.



I²C Bus Data Transfer

Data is transferred on the I²C bus in 8 bit packets, first transmitting the MSB which is the most significant bit and lastly the LSB bit, the least significant bit. When the data has been setup on the SDA line, the SCL line then generates a high pulse to latch the data. When the SCL line is high the SDA line is not permitted to change state. After 8-bits have been transmitted, the device will then send a 9th bit which is the acknowledge bit. Therefore in total there are 9 bits transmitted and subsequently 9 SCL clock pulses to transfer each 8-bits or byte of data. When the receiving device sends back a low ACK bit, this is to acknowledge that it has received the 8-bits of data and is ready to receive another byte. If a high ACK bit is sent back, this indicates that it is unable to receive any further data and the master should then send a stop sequence.

I²C Register Write/Read

Write Process

Bit	7	6	5	4	3	2	1	0		7	6	5	4	3	2	1	0		7	6	5	4	3	2	1	0		
Start	Device Address							Write	ACK	Register Address								ACK	Register Data								ACK	Stop

Read Process

Bit	7	6	5	4	3	2	1	0		7	6	5	4	3	2	1	0			7	6	5	4	3	2	1	0		7	6	5	4	3	2	1	0		
Start	Device Address							Write	ACK	Register Address								ACK	Start	Device Address							Read	ACK	Register Data								ACK	Stop

I²C Bus Start Signal

The START signal can only be generated by the master device connected to the I²C bus and not by the slave device. This START signal will be detected by all devices connected to the I²C bus. A START condition occurs when a high to low transition on the SDA line takes place when the SCL line remains high.

Slave Address

The transmission of a START signal by the master will be detected by all devices on the I²C bus. To determine which slave device the master wishes to communicate with, the address of the slave device will be sent out immediately following the START signal.

I²C Bus Slave Address Acknowledge Signal

After the master has transmitted a calling address, any slave device on the I²C bus, whose own internal address matches the calling address, must generate an acknowledge signal. The acknowledge signal will inform the master that a slave device has accepted its calling address. If no acknowledge signal is received by the master then a STOP signal must be transmitted by the master to end the communication.

I²C Bus Data and Acknowledge Signal

The transmitted data is 8-bits wide and is transmitted after the slave device has acknowledged receipt of its slave address. The order of serial bit transmission is the MSB first and the LSB last. After receipt of 8-bits of data, the receiver must transmit an acknowledge signal, level 0, before it can receive the next data byte. If the slave transmitter does not receive an acknowledge bit signal from the master receiver, then the slave transmitter will release the SDA line to allow the master to send a STOP signal to release the I²C Bus.

I²C Timeout Function

The I²C interface includes a timeout function which is controlled by a single register. This register sets the overall enable/disable function as well as the timeout value in ADC clock units. Determining whether the I²C bus has timed out is implemented by reading the SIMTOF bit. This bit will be automatically set high when the I²C bus times out, but needs to be cleared manually by the application program.

- **SIMTOC Register − 10H**

Bit	7	6	5	4	3	2	1	0
Name	SIMTOEN	SIMTOF	SIMTOS5	SIMTOS4	SIMTOS3	SIMTOS2	SIMTOS1	SIMTOS0
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
POR	0	0	0	0	0	0	0	0

Bit 7 **SIMTOEN**: I²C time-out control
0: Disable
1: Enable

Bit 6 **SIMTOF**: I²C time-out flag
0: Not occurred
1: Occurred
The bit is set by time-out function and is cleared by the application program.

Bit 5~0 **SIMTOS5~SIMTOS0**: I²C time-out selection time
The I²C Time-Out clock source is $f_{SUB}/32$. ($f_{SUB} = f_{ADC}/128$)
The I²C Time-Out time is ([SIMTOS5:SIMTOS0] + 1) × ($32/f_{SUB}$)

5 Pin Assignment

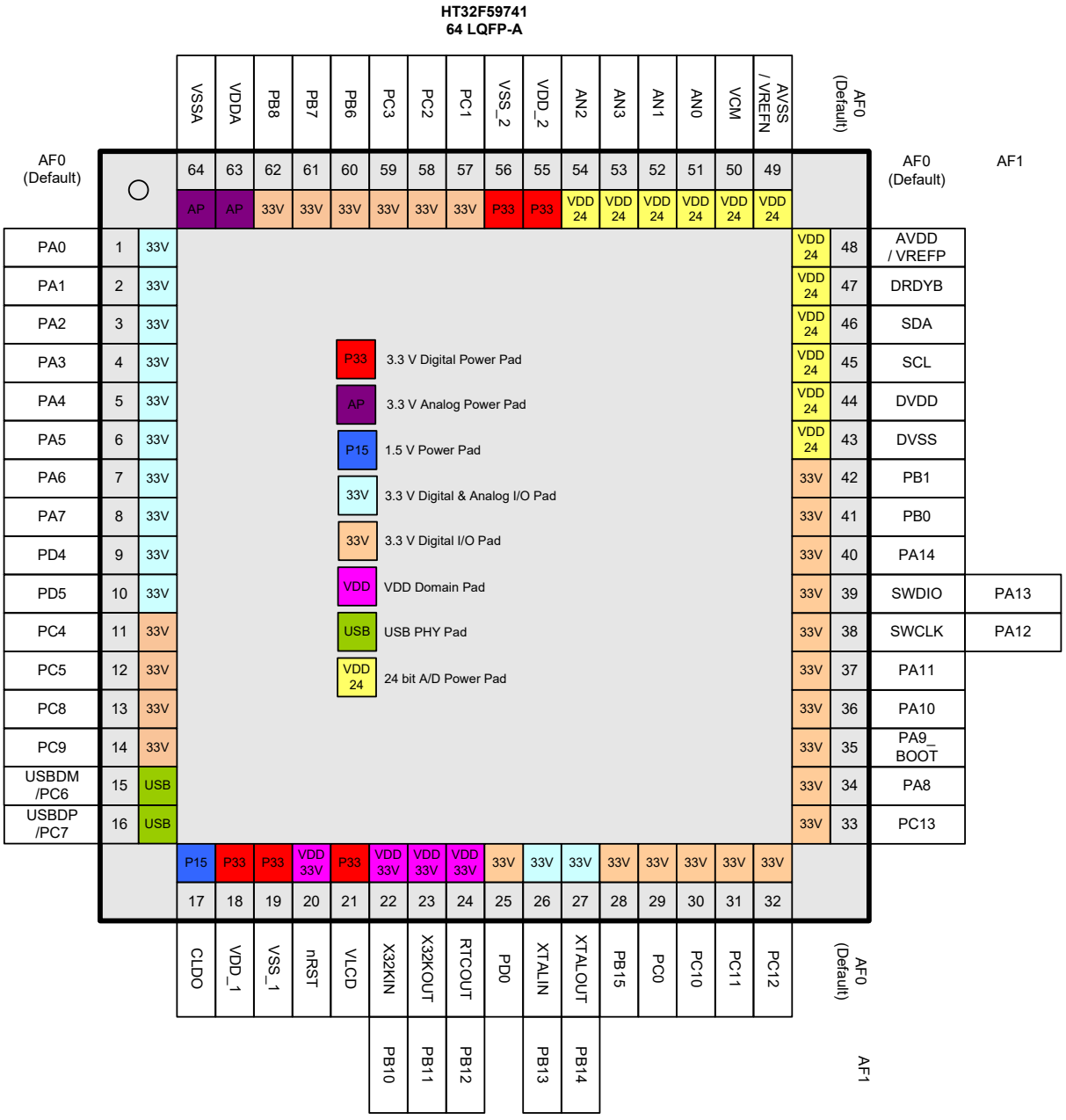


Figure 5. 64-pin LQFP Pin Assignment

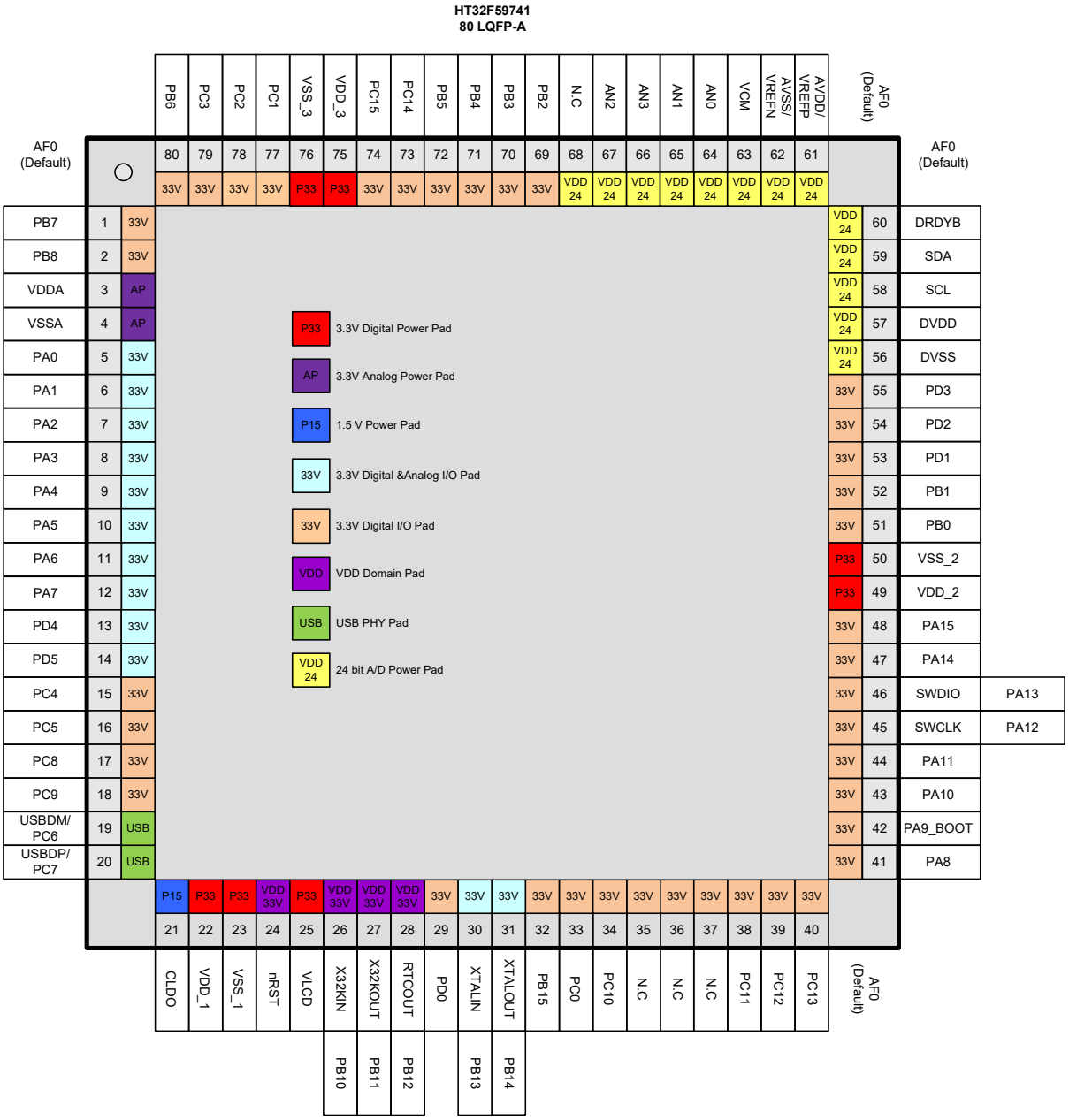


Figure 6. 80-pin LQFP Pin Assignment

Table 3. Pin Assignment

Package		Alternate Function Mapping															
		AF0	AF1	AF2	AF3	AF4	AF5	AF6	AF7	AF8	AF9	AF10	AF11	AF12	AF13	AF14	AF15
64 LQFP	80 LQFP	System Default	GPIO	ADC	N/A	GPTM	SPI	USART /UART	I²C	SCI	N/A	N/A	N/A	N/A	PWM	LCD	System Other
1	5	PA0		ADC_IN0		GT_CH0	SPI1_SCK	USR_RTS	I2C1_SCL	SCI_CLK							VREF
2	6	PA1		ADC_IN1		GT_CH1	SPI1_MOSI	USR_CTS	I2C1_SDA	SCI_DIO							
3	7	PA2		ADC_IN2		GT_CH2	SPI1_MISO	USR_TX									
4	8	PA3		ADC_IN3		GT_CH3	SPI1_SEL	USR_RX									
5	9	PA4		ADC_IN4		GT_CH0	SPI0_SCK	USR_TX	I2C0_SCL	SCI_CLK							
6	10	PA5		ADC_IN5		GT_CH1	SPI0_MOSI	USR_RX	I2C0_SDA	SCI_DIO							
7	11	PA6		ADC_IN6		GT_CH2	SPI0_MISO	USR_RTS		SCI_DET							
8	12	PA7		ADC_IN7		GT_CH3	SPI0_SEL	USR_CTS									
9	13	PD4		ADC_IN8				UR1_TX							PWM1_CH0		
10	14	PD5		ADC_IN9				UR1_RX							PWM1_CH1		
11	15	PC4				GT_CH0	SPI1_SEL	USR_TX	I2C1_SCL							SEG11	
12	16	PC5				GT_CH1	SPI1_SCK	USR_RX	I2C1_SDA							SEG12	
13	17	PC8				GT_CH2	SPI1_MOSI	UR1_TX								SEG13	
14	18	PC9				GT_CH3	SPI1_MISO	UR1_RX								SEG14	
15	19	PC6						UR0_TX	I2C0_SCL								
15	19	USBDM															
16	20	USBDP															
16	20	PC7						UR0_RX	I2C0_SDA								
17	21	CLDO															
18	22	VDD_1															
19	23	VSS_1															
20	24	nRST															
21	25	VLCD															
22	26	X32KIN	PB10					USR_TX									
23	27	X32KOUT	PB11					USR_RX									
24	28	RTCOUT	PB12														WAKEUP
25	29	PD0							I2C0_SDA							SEG15	
26	30	XTALIN	PB13														
27	31	XTALOUT	PB14														
28	32	PB15					SPI0_SEL	USR_TX	I2C1_SCL						PWM0_CH2	COM0	
29	33	PC0					SPI0_SCK	USR_RX	I2C1_SDA						PWM0_CH3	COM1	
30	34	PC10				GT_CH0	SPI1_SEL									SEG25 /COM4	

Package		Alternate Function Mapping															
		AF0	AF1	AF2	AF3	AF4	AF5	AF6	AF7	AF8	AF9	AF10	AF11	AF12	AF13	AF14	AF15
64 LQFP	80 LQFP	System Default	GPIO	ADC	N/A	GPTM	SPI	USART /UART	I²C	SCI	N/A	N/A	N/A	N/A	PWM	LCD	System Other
31	38	PC11				GT_ CH1	SPI1_ SCK									SEG26 /COM5	
32	39	PC12				GT_ CH2	SPI1_ MOSI	UR1_ TX	I2C0_ SCL							SEG27 /COM6	
33	40	PC13				GT_ CH3	SPI1_ MISO	UR1_ RX	I2C0_ SDA							SEG28 /COM7	
34	41	PA8						USR_ TX							PWM1_ CH3	COM2	
35	42	PA9_ BOOT					SPI0_ MOSI								PWM1_ CH2		CKOUT
36	43	PA10						USR_ RX		SCI_ DET					PWM0_ CH1	COM3	
37	44	PA11					SPI0_ MISO									SEG0	
38	45	SWCLK	PA12														
39	46	SWDIO	PA13														
40	47	PA14					SPI1_ SEL	USR_ RTS	I2C1_ SCL	SCI_ CLK					PWM0_ CH0	SEG1	
	48	PA15					SPI1_ SCK	USR_ CTS	I2C1_ SDA	SCI_ DIO						SEG2	
41	51	PB0					SPI1_ MOSI	USR_ TX	I2C0_ SCL						PWM0_ CH1	SEG3	
42	52	PB1					SPI1_ MISO	USR_ RX	I2C0_ SDA						PWM1_ CH1	SEG4	
	53	PD1						USR_ RTS		SCI_ CLK						SEG16	
	54	PD2						USR_ CTS		SCI_ DIO						SEG17	
	55	PD3								SCI_ DET						SEG18	
43	56	DVSS															
44	57	DVDD															
45	58	SCL															
46	59	SDA															
47	60	DRDYB															
48	61	AVDD															
48	61	VREFP															
49	62	AVSS															
49	62	VREFN															
50	63	VCM															
51	64	AN0															
52	65	AN1															
53	66	AN3															
54	67	AN2															
	69	PB2					SPI0_ SEL	UR0_ TX							PWM0_ CH2	SEG5	CKIN
	70	PB3					SPI0_ SCK	UR0_ RX								SEG6	
	71	PB4					SPI0_ MOSI	UR1_ TX								SEG7	
	72	PB5					SPI0_ MISO	UR1_ RX								SEG8	
	73	PC14							I2C0_ SCL							SEG9	

Package		Alternate Function Mapping														
		AF0	AF1	AF2	AF3	AF4	AF5	AF6	AF7	AF8	AF9	AF10	AF11	AF12	AF13	AF14	AF15
64 LQFP	80 LQFP	System Default	GPIO	ADC	N/A	GPTM	SPI	USART /UART	I^2C	SCI	N/A	N/A	N/A	N/A	PWM	LCD	System Other
	74	PC15							I2C0_ SDA							SEG10	
	75	VDD_3															
	76	VSS_3															
55	49	VDD_2															
56	50	VSS_2															
57	77	PC1					SPI1_ SEL	UR1_ TX							PWM0_ CH0	SEG19	
58	78	PC2					SPI1_ SCK								PWM1_ CH0	SEG20	
59	79	PC3					SPI1_ MOSI	UR1_ RX							PWM1_ CH2	SEG21	
60	80	PB6					SPI1_ MISO	UR0_ TX		SCI_ CLK						SEG22	
61	1	PB7							I2C1_ SCL	SCI_ DET					PWM0_ CH3	SEG23	
62	2	PB8						UR0_ RX	I2C1_ SDA	SCI_ DIO					PWM1_ CH3	SEG24	
63	3	VDDA															
64	4	VSSA															

Table 4. Pin Description

Pin Number		Pin Name	Type(1)	I/O Structure(2)	Output Driving	Description
64 LQFP	80 LQFP					Default Function (AF0)
1	5	PA0	AI/O	33V	4/8/12/16 mA	PA0
2	6	PA1	AI/O	33V	4/8/12/16 mA	PA1
3	7	PA2	AI/O	33V	4/8/12/16 mA	PA2
4	8	PA3	AI/O	33V	4/8/12/16 mA	PA3
5	9	PA4	AI/O	33V	4/8/12/16 mA	PA4
6	10	PA5	AI/O	33V	4/8/12/16 mA	PA5
7	11	PA6	AI/O	33V	4/8/12/16 mA	PA6
8	12	PA7	AI/O	33V	4/8/12/16 mA	PA7
9	13	PD4	AI/O	33V	4/8/12/16 mA	PD4
10	14	PD5	AI/O	33V	4/8/12/16 mA	PD5
11	15	PC4	I/O	33V	4/8/12/16 mA	PC4
12	19	PC5	I/O	33V	4/8/12/16 mA	PC5
13	17	PC8	I/O	33V	4/8/12/16 mA	PC8
14	18	PC9	I/O	33V	4/8/12/16 mA	PC9
15	19	PC6	I/O	33V	4/8/12/16 mA	PC6
15	19	USBDM	AI/O	—	—	USB Differential data bus conforming to the Universal Serial Bus standard.
16	20	USBDP	AI/O	—	—	USB Differential data bus conforming to the Universal Serial Bus standard.
16	20	PC7	I/O	33V	4/8/12/16 mA	PC7
17	21	CLDO	P	—	—	Core power LDO 1.5 V output It must be connected a 2.2 μF capacitor as close as possible between this pin and VSS_1.
18	22	VDD_1	P	—	—	Voltage for digital I/O
19	23	VSS_1	P	—	—	Ground reference for digital I/O
20	24	nRST(3)	I (V_{DD})	33V_PU	—	External reset pin and external wakeup pin in the Power-Down mode.
21	25	VLCD	P	—	—	Voltage for LCD power supply It must be connected a 2.2 μF capacitor as close as possible between this pin and VSS_1 for LCD supply power with internal charge pump mode, or connected a general bypass capacitor for external LCD supply power.
22	26	PB10(3)	AI/O (V_{DD})	33V	4/8/12/16 mA	X32KIN
23	27	PB11(3)	AI/O (V_{DD})	33V	4/8/12/16 mA	X32KOUT
24	28	PB12(3)	I/O (V_{DD})	33V	4/8/12/16 mA	RTCOUT
25	29	PD0	I/O	33V	4/8/12/16 mA	PD0
26	30	PB13	AI/O	33V	4/8/12/16 mA	XTALIN
27	31	PB14	AI/O	33V	4/8/12/16 mA	XTALOUT
28	32	PB15	I/O	33V	4/8/12/16 mA	PB15

Pin Number		Pin Name	Type(1)	I/O Structure(2)	Output Driving	Description
64 LQFP	80 LQFP					Default Function (AF0)
29	33	PC0	I/O	33V	4/8/12/16 mA	PC0
30	34	PC10	I/O	33V	4/8/12/16 mA	PC10
31	38	PC11	I/O	33V	4/8/12/16 mA	PC11
32	39	PC12	I/O	33V	4/8/12/16 mA	PC12
33	40	PC13	I/O	33V	4/8/12/16 mA	PC13
34	41	PA8	I/O	33V	4/8/12/16 mA	PA8
35	42	PA9	I/O	33V_PU	4/8/12/16 mA	PA9_BOOT
36	43	PA10	I/O	33V	4/8/12/16 mA	PA10
37	44	PA11	I/O	33V	4/8/12/16 mA	PA11
38	45	PA12	I/O	33V_PU	4/8/12/16 mA	SWCLK
39	46	PA13	I/O	33V_PU	4/8/12/16 mA	SWDIO
40	47	PA14	I/O	33V	4/8/12/16 mA	PA14
	48	PA15	I/O	33V	4/8/12/16 mA	PA15
41	51	PB0	I/O	33V	4/8/12/16 mA	PB0
42	52	PB1	I/O	33V	4/8/12/16 mA	PB1
	53	PD1	I/O	33V	4/8/12/16 mA	PD1
	54	PD2	I/O	33V	4/8/12/16 mA	PD2
	55	PD3	I/O	33V	4/8/12/16 mA	PD3
43	56	DVSS	P	—	—	Ground reference for 24-bit ADC module
44	57	DVDD	P	—	—	Digital power supply for 24-bit ADC module
45	58	SCL	I	—	—	24-bit ADC module I^2C interface clock line
46	59	SDA	I/O	—	—	24-bit ADC module I^2C interface data line
47	60	DRDYB	O	—	—	24-bit ADC data ready indication. Indicates valid data by going low
48	61	AVDD	P	—	—	24-bit ADC analogy positive power supply
48	61	VREFP	AI	—	—	24-bit ADC positive reference input
49	62	VREFN	AI	—	—	24-bit ADC negative reference input
49	62	AVSS	P	—	—	24-bit ADC analogy negative power supply
50	63	VCM	AO	—	—	24-bit ADC internal Common Mode voltage output
51	64	AN0	AI	—	—	24-bit ADC input channel 0
52	65	AN1	AI	—	—	24-bit ADC input channel 1
53	66	AN3	AI	—	—	24-bit ADC input channel 3
54	67	AN2	AI	—	—	24-bit ADC input channel 2
	69	PB2	I/O	33V	4/8/12/16 mA	PD1
	70	PB3	I/O	33V	4/8/12/16 mA	PD2
	71	PB4	I/O	33V	4/8/12/16 mA	PD3
	72	PB5	I/O	33V	4/8/12/16 mA	
	73	PC14	I/O	33V	4/8/12/16 mA	
	74	PC15	I/O	33V	4/8/12/16 mA	
	75	VDD_3	P	—	—	Voltage for digital I/O

Pin Number		Pin Name	Type(1)	I/O Structure(2)	Output Driving	Description
64 LQFP	80 LQFP					Default Function (AF0)
	76	VSS_3	P	—	—	Ground reference for digital I/O
55	49	VDD_2	P	—	—	Voltage for digital I/O
56	50	VSS_2	P	—	—	Ground reference for digital I/O
57	77	PC1	I/O	33V	4/8/12/16 mA	PC1
58	78	PC2	I/O	33V	4/8/12/16 mA	PC2
59	79	PC3	I/O	33V	4/8/12/16 mA	PC3
60	80	PB6	I/O	33V	4/8/12/16 mA	PB6
61	1	PB7	I/O	33V	4/8/12/16 mA	PB7
62	2	PB8	I/O	33V	4/8/12/16 mA	PB8
63	3	VDDA	P	—	—	Analog voltage for 12-bit ADC
64	4	VSSA	P	—	—	Ground reference for 12-bit ADC

Note: 1. I = Input, O = Output, A = Analog Port, P = Power Supply, V_{DD} = V_{DD} Power.
2. 33V = 3.3 V tolerant, PU = Pull-up.
3. These pins are located at the V_{DD} power domain.

6 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 5. Absolute Maximum Ratings

Symbol	Parameter	Min.	Max.	Unit
V_{DD}	External Main Supply Voltage	V_{SS} - 0.3	V_{SS} + 3.6	V
V_{DDA}	External Analog Supply Voltage	V_{SSA} - 0.3	V_{SSA} + 3.6	V
V_{LCD}	LCD Supply Voltage	V_{SS} - 0.3	V_{SS} + 3.6	V
V_{IN}	Input Voltage on I/O	V_{SS} - 0.3	V_{DD} + 0.3	V
DV_{DD}	24-bit A/D Converter Module Supply Voltage	DV_{SS} - 0.3	DV_{SS} + 6.0	V
T_A	Ambient Operating Temperature Range	-40	85	°C
T_{STG}	Storage Temperature Range	-60	150	°C
T_J	Maximum Junction Temperature	—	125	°C
P_D	Total Power Dissipation	—	500	mW
V_{ESD}	Electrostatic Discharge Voltage – Human Body Mode	-4000	+4000	V

Recommended DC Operating Conditions

Table 6. Recommended DC Operating Conditions

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{DD}	Operating Voltage	—	1.65	3.3	3.6	V
V_{DDA}	Analog Operating Voltage	—	2.5	3.3	3.6	V
V_{LCD}	LCD Operating Voltage	—	2.2	3.3	3.6	V

On-Chip LDO Voltage Regulator Characteristics

Table 7. LDO Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{LDO}	Internal Regulator Output Voltage	V_{DD} ≥ 1.65 V Regulator input @ I_{LDO} = 10 mA and voltage variant = ± 5 %, after trimming	1.425	1.5	1.57	V
I_{LDO}	Output Current	V_{DD} = 2.0 V ~ 3.6 V Regulator input @ V_{LDO} = 1.5 V	—	30	35	mA
		V_{DD} = 1.65 V ~ 2.0 V Regulator input @ V_{LDO} = 1.5 V	—	20	25	

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
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	—	μF

On-Chip Ultra-low Power LDO Voltage Regulator Characteristics

Table 8. ULDO Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{ULDO}	Internal Regulator Output Voltage	V_{DD} ≥ 1.65 V Regulator input @ I_{ULDO} = 2 mA and voltage variant = ±5 %, after trimming	1.425	1.5	1.57	V
I_{ULDO}	Output Current	V_{DD} = 1.65 V ~ 3.6 V Regulator input @ V_{ULDO} = 1.5 V	—	2	5	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	—	μF

Power Consumption

Table 9. Power Consumption Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	f_{HCLK}	Conditions		Typ.	Max. @ T_A		Unit
						25 °C	85 °C	
I_{DD}	Run Mode	60 MHz	V_{DD} = V_{LCD} = 3.3 V, HSI = 8 MHz, PLL = 60 MHz	All peripherals enabled	14.9	17.0	—	mA
				All peripherals disabled	6.9	7.9	—	
		40 MHz	V_{DD} = V_{LCD} = 3.3 V, HSI = 8 MHz, PLL = 40 MHz	All peripherals enabled	11.9	13.6	—	
				All peripherals disabled	6.5	7.4	—	
		20 MHz	V_{DD} = V_{LCD} = 3.3 V, HSI = 8 MHz, PLL = 40 MHz	All peripherals enabled	6.2	7.1	—	
				All peripherals disabled	3.2	3.6	—	
		8 MHz	V_{DD} = V_{LCD} = 3.3 V, HSI = 8 MHz, PLL = off	All peripherals enabled	3.2	3.6	—	
				All peripherals disabled	1.4	1.6	—	
		32 kHz	V_{DD} = V_{LCD} = 3.3 V, LSI = 32 kHz, LDO off, ULDO on	All peripherals enabled	13.2	17.5	—	μA
				All peripherals disabled	9.2	12.2	—	

Symbol	Parameter	f_{HCLK}	Conditions		Typ.	Max. @ T_A		Unit
						25 °C	85 °C	
I_{DD}	Sleep Mode	60 MHz	V_{DD} = V_{LCD} = 3.3 V, HSI = 8 MHz, PLL = 60 MHz	All peripherals enabled	10.3	11.8	—	mA
				All peripherals disabled	1.5	1.7	—	
		40 MHz	V_{DD} = V_{LCD} = 3.3 V, HSI = 8 MHz, PLL = 40 MHz	All peripherals enabled	7.1	8.1	—	
				All peripherals disabled	1.2	1.3	—	
		20 MHz	V_{DD} = V_{LCD} = 3.3 V, HSI = 8 MHz, PLL = 40 MHz	All peripherals enabled	4.2	4.8	—	
				All peripherals disabled	0.9	1.0	—	
		8 MHz	V_{DD} = V_{LCD} = 3.3 V, HSI = 8 MHz, PLL = off	All peripherals enabled	2.4	2.7	—	
				All peripherals disabled	0.4	0.5	—	
I_{DD}	Deep-Sleep 1 Mode	—	V_{DD} = V_{LCD} = 3.3 V, HSI/HSE/PLL clock off, LDO off, ULDO on, LSE off, LSI on, RTC on		5.0	7.6	—	µA
	Deep-Sleep 2 Mode	—	V_{DD} = V_{LCD} = 3.3 V, HSI/HSE/PLL clock off, LDO off, ULDO on, LSE off, LSI on, RTC on, LDO off		5.0	7.6	—	µA
			V_{DD} = V_{LCD} = 3.3 V, HSI/HSE/PLL clock off, LDO off, ULDO on, LSE off, LSI on, RTC off, LCD on(5), external V_{LCD} = V_{DD}		7.5	—	—	
			V_{DD} = 2.7 V, V_{LCD} = 3.25 V, HSI/HSE/PLL clock off, LDO off, ULDO on, LSE off, LSI on, RTC off, LCD on(6), internal V_{LCD} pump		55.3	—	—	
	Power-Down Mode	—	V_{DD} = V_{LCD} = 3.3 V, LDO and ULDO off, LSE off, LSI on, RTC on		1.40	2.15	—	µA
			V_{DD} = V_{LCD} = 3.3 V, LDO and ULDO off, LSE off, LSI on, RTC off		1.30	1.30	—	

Note: 1. HSE means high speed external oscillator. HSI means 8 MHz high speed internal oscillator.
2. LSE means 32.768 kHz low speed external oscillator. LSI means 32 kHz low speed internal oscillator.
3. RTC means real time clock.
4. Code = while (1) { 208 NOP } executed in Flash.
5. LCD enabled with external VLCD, 1/4 duty, 1/3 bias, division ratio = 64, high drive disabled, all pixels active, no LCD connected.
6. LCD enabled with internal VLCD, 1/4 duty, 1/3 bias, division ratio = 64, high drive disabled, all pixels active, no LCD connected.

Reset and Supply Monitor Characteristics

Table 10. V_{DD} Power Reset Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{DD}	Operation Voltage	T_A = -40 °C ~ 85 °C	0.6	—	3.6	V
V_{POR}	Power On Reset Threshold (Rising Voltage on V_{DD})	T_A = -40 °C ~ 85 °C	1.4	1.55	1.65	V
V_{PDR}	Power Down Reset Threshold (Falling Voltage on V_{DD})	T_A = -40 °C ~ 85 °C	1.27	1.45	1.57	V
$V_{PORHYST}$	POR Hysteresis	—	—	100	—	mV
t_{POR}	Reset Delay Time	V_{DD} = 3.3 V	—	0.1	0.2	ms

Note: 1. Data based on characterization results only, not tested in production.
2. Guaranteed by design, not tested in production.
3. 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 and ULDO will be turned off.

Table 11. 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	1.62	1.68	1.74	V
			V_{DD} Rising edge	1.68	1.74	1.8	
$V_{BODHYST}$	BOD Hysteresis	V_{DD} = 2.0 V	—	—	60	—	mV
V_{LVD}	Voltage of Low Voltage Detection	V_{DD} Falling edge	LVDS = 000	1.67	1.75	1.83	V
			LVDS = 001	1.87	1.95	2.03	V
			LVDS = 010	2.07	2.15	2.23	V
			LVDS = 011	2.27	2.35	2.43	V
			LVDS = 100	2.47	2.55	2.63	V
			LVDS = 101	2.67	2.75	2.83	V
			LVDS = 110	2.87	2.95	3.03	V
			LVDS = 111	3.07	3.15	3.23	V
$V_{LVDHYST}$	LVD Hysteresis	V_{DD} = 3.3 V	—	—	100	—	mV
t_{suLVD}	LVD Setup Time	V_{DD} = 3.3 V	—	—	—	5	μs
t_{atLVD}	LVD Active Delay Time	V_{DD} = 3.3 V	—	—	—	—	ms
I_{DDLVD}	Operation Current (3)	V_{DD} = 3.3 V	—	—	5	15	μA

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

External Clock Characteristics

Table 12. High Speed External Clock (HSE) Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{DD}	Operation Voltage Range	—	1.65	—	3.6	V
f_{CK_HSE}	HSE Frequency	—	4	—	16	MHz
C_L	Load Capacitance	V_{DD} = 3.3 V, R_{ESR} = 100 Ω @ 16 MHz	—	—	22	pF
R_{FHSE}	Internal Feedback Resistor between XTALIN and XTALOUT pins	—	—	1	—	MΩ
R_{ESR}	Equivalent Series Resistance	V_{DD} = 3.3 V, C_L = 12 pF @ 16 MHz, HSEDR = 0	—	—	160	Ω
		V_{DD} = 2.5 V, C_L = 12 pF @ 16 MHz, HSEDR = 1				
D_{HSE}	HSE Oscillator Duty Cycle	—	40	—	60	%
I_{DDHSE}	HSE Oscillator Current Consumption	V_{DD} = 3.3 V @ 16 MHz	—	TBD	—	mA
I_{PWDHSE}	HSE Oscillator Power Down Current	V_{DD} = 3.3 V	—	—	0.01	μA
t_{SUHSE}	HSE Oscillator Startup Time	V_{DD} = 3.3 V	—	—	4	ms

Table 13. Low Speed External Clock (LSE) Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{DD}	Operation Voltage Range	—	1.65	—	3.6	V
f_{CK_LSE}	LSE Frequency	V_{DD} = 1.65 V ~ 3.6 V	—	32.768	—	kHz
R_F	Internal Feedback Resistor	—	—	10	—	MΩ
R_{ESR}	Equivalent Series Resistance	V_{DD} = 3.3 V	30	—	TBD	kΩ
C_L	Recommended Load Capacitances	V_{DD} = 3.3 V	6	—	TBD	pF
I_{DDLSE}	Oscillator Supply Current (High Current Mode)	f_{CK_LSE} = 32.768 kHz R_{ESR} = 50 kΩ, C_L ≥ 7 pF V_{DD} = 1.65 V ~ 2.7 V T_A = -40 °C ~ 85 °C	—	3.3	6.3	μA
	Oscillator Supply Current (Low Current Mode)	f_{CK_LSE} = 32.768 kHz R_{ESR} = 50 kΩ, C_L < 7 pF V_{DD} = 1.65 V ~ 3.6 V T_A = -40 °C ~ 85 °C	—	1.8	3.3	μA
	LSE Oscillator Power Down Current	—	—	—	0.01	μA
t_{SULSE}	LSE Oscillator Startup Time (Low Current Mode)	f_{CK_LSE} = 32.768 kHz, V_{DD} = 1.65 V ~ 3.6 V	500	—	—	ms

Note: The following guidelines are recommended to increase the stability of the crystal circuit of the HSE / LSE clock in the PCB layout.

1. The crystal oscillator should be located as close as possible to the MCU to keep the trace length as short as possible to reduce the parasitic capacitance.
2. Shield lines in the vicinity of the crystal by using a ground plane to isolate signals and reduce noise.
3. Keep the high frequency signal lines away from the crystal area to prevent the crosstalk adverse effects.

Internal Clock Characteristics

Table 14. High Speed Internal Clock (HSI) Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{DD}	Operation Voltage Range	T_A = -40 °C ~ 85 °C	1.65	—	3.6	V
f_{CK_HSI}	HSI Frequency	V_{DD} = 3.3 V	—	8	—	MHz
ACC_{HSI}	Factory Calibrated HSI Oscillator Frequency Accuracy	V_{DD} = 3.3 V, T_A = 25 °C	-1	—	1	%
		V_{DD} = 1.65 V ~ 3.6 V T_A = -20 °C ~ 60 °C	-2.5	—	2.5	%
		V_{DD} = 1.65 V ~ 3.6 V T_A = -40 °C ~ 85 °C	-3	—	3	%
Duty	Duty Cycle	f_{CK_HSI} = 8 MHz	35	—	65	%
I_{DDHSI}	Oscillator Supply Current	f_{CK_HSI} = 8 MHz	—	300	500	μA
	HSI Oscillator Power Down Current		—	—	0.05	μA
t_{SUHSI}	HSI Oscillator Startup Time	f_{CK_HSI} = 8 MHz	—	—	10	μs

Table 15. Low Speed Internal Clock (LSI) Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{DD}	Operation Voltage Range	—	1.65	—	3.6	V
f_{CK_LSI}	LSI Frequency	V_{DD} = 3.3 V, T_A = -40 °C ~ 85 °C	21	32	43	kHz
ACC_{LSI}	LSI Frequency Accuracy	After factory-trimmed, V_{DD} = 3.3 V, T_A = 25 °C	-10	—	+10	%
I_{DDLSI}	LSI Oscillator Operating Current	V_{DD} = 3.3 V, T_A = 25 °C	—	0.4	0.8	μA
t_{SULSI}	LSI Oscillator Startup Time	V_{DD} = 3.3 V, T_A = 25 °C	—	—	100	μs

System PLL Characteristics

Table 16. System PLL Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
f_{PLLIN}	System PLL Input Clock	—	4	—	16	MHz
f_{CK_PLL}	System PLL Output Clock	—	16	—	60	MHz
t_{LOCK}	System PLL Lock Time	—	—	200	—	μs

USB PLL Characteristics

Table 17. USB PLL Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
f_{PLLIN}	USB PLL Input Clock	—	4	—	16	MHz
f_{CK_PLL}	USB PLL Output Clock	—	64	—	96	MHz
t_{LOCK}	USB PLL Lock Time	—	—	200	—	μs

Memory Characteristics

Table 18. Flash Memory Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
N_{ENDU}	Number of Guaranteed Program/Erase Cycles before failure (Endurance)	T_A = -40 °C ~ 85 °C	10	—	—	K cycles
t_{RET}	Data Retention Time	T_A = -40 °C ~ 85 °C	10	—	—	Years
t_{PROG}	Word Programming Time	T_A = -40 °C ~ 85 °C	20	—	—	μs
t_{ERASE}	Page Erase Time	T_A = -40 °C ~ 85 °C	2	—	—	ms
t_{MERASE}	Mass Erase Time	T_A = -40 °C ~ 85 °C	10	—	—	ms

I/O Port Characteristics

Table 19. I/O Port Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
I_{IL}	Low Level Input Current	3.3 V I/O	V_I = V_{SS}, On-chip pull-up resistor disabled	—	—	3	μA
		Reset pin		—	—	3	
I_{IH}	High Level Input Current	3.3 V I/O	V_I = V_{DD}, On-chip pull-down resistor disabled	—	—	3	μA
		Reset pin		—	—	3	
V_{IL}	Low Level Input Voltage	3.3 V I/O		- 0.4	—	V_{DD} × 0.35	V
		Reset pin		- 0.4	—	V_{DD} × 0.35	
V_{IH}	High Level Input Voltage	3.3 V I/O		V_{DD} × 0.65	—	V_{DD} + 0.4	V
		Reset pin		V_{DD} × 0.65	—	V_{DD} + 0.4	
V_{HYS}	Schmitt Trigger Input Voltage Hysteresis	3.3 V I/O		—	0.12 × V_{DD}	—	mV
		Reset pin		—	0.12 × V_{DD}	—	

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
I_{OL}	Low Level Output Current (GPIO Sink Current)	3.3 V I/O 4 mA drive, V_{OL} = 0.4 V	4	—	—	mA
		3.3 V I/O 8 mA drive, V_{OL} = 0.4 V	8	—	—	
		3.3 V I/O 12 mA drive, V_{OL} = 0.4 V	12	—	—	
		3.3 V I/O 16 mA drive, V_{OL} = 0.4 V	16	—	—	
I_{OH}	High Level Output Current (GPIO Source Current)	3.3 V I/O 4 mA drive, V_{OH} = V_{DD} - 0.4 V	4	—	—	mA
		3.3 V I/O 8 mA drive, V_{OH} = V_{DD} - 0.4 V	8	—	—	
		3.3 V I/O 12 mA drive, V_{OH} = V_{DD} - 0.4 V	12	—	—	
		3.3 V I/O 16 mA drive, V_{OH} = V_{DD} - 0.4 V	16	—	—	
V_{OL}	Low Level Output Voltage	3.3 V 4 mA drive I/O, I_{OL} = 4 mA	—	—	0.4	V
		3.3 V 8 mA drive I/O, I_{OL} = 8 mA	—	—	0.4	
		3.3 V 12 mA drive I/O, I_{OL} = 12 mA	—	—	0.4	
		3.3 V 16 mA drive I/O, I_{OL} = 16 mA	—	—	0.4	
V_{OH}	High Level Output Voltage	3.3 V 4 mA drive I/O, I_{OH} = 4 mA	V_{DD} - 0.4	—	—	V
		3.3 V 8 mA drive I/O, I_{OH} = 8 mA	V_{DD} - 0.4	—	—	
		3.3 V 12 mA drive I/O, I_{OH} = 12 mA	V_{DD} - 0.4	—	—	
		3.3 V 16 mA drive I/O, I_{OH} = 16 mA	V_{DD} - 0.4	—	—	
R_{PU}	Internal Pull-up Resistor	3.3 V I/O, V_{DD} = 3.3 V	—	60	—	kΩ
R_{PD}	Internal Pull-down Resistor	3.3 V I/O, V_{DD} = 3.3 V	—	60	—	kΩ

12-Bit ADC Characteristics

Table 20. ADC Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{DDA}	A/D Converter Operating Voltage	—	2.5	3.3	3.6	V
V_{ADCIN}	A/D Converter Input Voltage Range	—	0	—	V_{REF+}	V
V_{REF+}	A/D Converter Reference Voltage	—	—	V_{DDA}	V_{DDA}	V
I_{ADC}	Current Consumption	V_{DDA} = 3.3 V	—	1	TBD	mA
I_{ADC_DN}	A/D Converter Power Down Current Consumption	V_{DDA} = 3.3 V	—	—	0.1	μA
f_{ADC}	A/D Converter Clock Frequency	—	0.7	—	16	MHz
f_S	Sampling Rate	—	0.05	—	1	MHz
t_{DL}	Data Latency	—	—	12.5	—	$1/f_{ADC}$ Cycles
$t_{S\&H}$	Sampling & Hold Time	—	—	3.5	—	$1/f_{ADC}$ Cycles

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$t_{ADCCONV}$	A/D Converter Conversion Time	—	—	16	—	$1/f_{ADC}$ Cycles
R_I	Input Sampling Switch Resistance	—	—	—	1	kΩ
C_I	Input Sampling Capacitance	No pin/pad capacitance included	—	4	—	pF
t_{SU}	Start Up Time	—	—	—	1	μs
N	Resolution	—	—	12	—	bits
INL	Integral Non-linearity Error	f_S = 750 kHz, V_{DDA} = 3.3 V	—	±2	±5	LSB
DNL	Differential Non-linearity Error	f_S = 750 kHz, V_{DDA} = 3.3 V	—	±1	—	LSB
E_O	Offset Error	—	—	—	±10	LSB
E_G	Gain Error	—	—	—	±10	LSB

Note: 1. Guaranteed by design, not tested in production.

2. The figure below shows the equivalent circuit of the A/D Converter Sample-and-Hold input stage where C_I is the storage capacitor, R_I 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_I, 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.

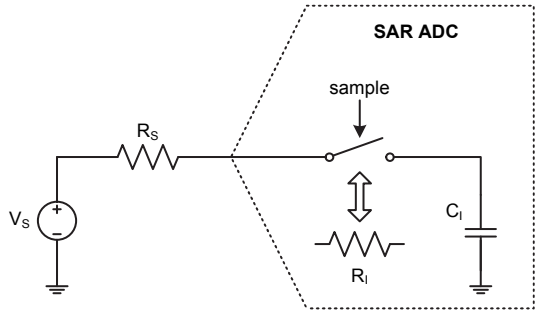


Figure 7. ADC Sampling Network Model

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 ¼ LSB is ensured by using the following equation:

$$R_S < \frac{3.5}{f_{ADC} C_I \ln(2^{N+2})} - R_I$$

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.

24-Bit ADC Characteristics

Table 21. 24-bit ADC Characteristics

$DV_{DD} = AV_{DD}$, $T_A = 25$ °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
AV_{DD}	Supply Voltage for VCM, ADC, PGA	—	2.4	—	3.6	V
V_{OUT_VCM}	VCM Output Voltage (VCM Pin)	AV_{DD} = 3.3V, No load	-5%	1.25	+5%	V
TC_{VCM}	VCM Temperature Coefficient	Ta = -40 °C ~ 85 °C, AV_{DD} = 3.3 V, I_{LOAD} = 10 μA	—	—	0.24	mV/°C
ΔV_{LINE_VCM}	VCM Line Regulation	2.4 V ≤ AV_{DD} ≤ 3.3 V, No load	—	—	0.4	%/V
t_{VCMS}	VCM Turn-on Stable Time	AV_{DD} = 3.3 V, No load	—	—	10	ms
I_{OH}	Source Current for VCM Pin	AV_{DD} = 3.3 V, ΔV_{OUT_VCM} = -2%	3	—	—	mA
I_{OL}	Sink Current for VCM Pin	AV_{DD} = 3.3 V, ΔV_{OUT_VCM} = +2%	3	—	—	mA
ADC & ADC Internal Reference Voltage (Sigma Delta ADC)						
I_{ADC}	Additional Current for ADC Enable	VCM enable, VRBUFP = 1 and VRBUFN = 1	—	—	1120	μA
		VCM enable, VRBUFP = 0 and VRBUFN = 0	—	820	970	μA
		VCM disable, VRBUFP = 0 and VRBUFN = 0	—	500	650	μA
I_{ADSTB}	Standby Current	ADC off, no load	—	—	1	μA
RS_{ADC}	Resolution	—	—	—	24	bit
INL	Integral Non-linearity	AV_{DD} = 3.3 V, V_{REF} = 1.25 V, ΔSI = ±450 mV, PGA Gain = 1	—	±50	—	ppm
NFB	Noise Free Bits	V_{REF} = 1.65 V, Gain = 32 Data rate = 10 Hz	—	17.5	—	Bit
		V_{REF} = 1.65 V, Gain = 64 Data rate = 10 Hz	—	16.8	—	Bit
		V_{REF} = 1.65 V, Gain = 128 Data rate = 10 Hz	—	16.0	—	Bit
ENOB	Effective Number of Bits	V_{REF} = 1.65 V, Gain = 32 Data rate = 10 Hz	—	20.2	—	Bit
		V_{REF} = 1.65 V, Gain = 64 Data rate = 10 Hz	—	19.5	—	Bit
		V_{REF} = 1.65 V, Gain = 128 Data rate = 10 Hz	—	18.7	—	Bit
f_{ADCK}	ADC Clock Frequency	—	40	409.6	440	kHz

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
f_{ADO}	ADC Output Data Rate	f_{MCLK} = 4.9152 MHz, FLMS[2:0] = 000B	5	—	640	Hz
		f_{MCLK} = 4.9152 MHz, FLMS[2:0] = 010B	12.5	—	1600	Hz
V_{REFP}	External Reference Input Voltage	VREFS = 1, VRBUFP = 0, VRBUFN = 0	V_{REFN}+1	—	AV_{DD}	V
V_{REFN}			0	—	V_{REFP}-1	V
V_{REF}		V_{REF} = (V_{REFP}–V_{REFN})×VGS	1	—	AV_{DD}/2	V
PGA						
V_{CM_PGA}	Common Mode Voltage Range	—	0.4	—	AV_{DD} -0.95	V
ΔD_I	Differentail Input Voltage Range	Gain = PGS×AGS, ΔD_I = DI+ - DI-	-V_{REF}/ Gain	—	+V_{REF}/ Gain	V
Temperature Sensor						
TC_{TS}	Temperature Sensor Temperature Coefficient	Ta = -40°C~85°C, V_{REF} = 1.25 V, VGS[1:0] = 00B (Gain = 1), VRBUFP = 0, VRBUFN = 0	—	175	—	μV/°C

Effective Number of Bits (ENOB)

V_{REF}=1.65V, f_{ADCK}=163kHz

Data Rate (SPS)	PGA Gain							
	1	2	4	8	16	32	64	128
5	21.5	21.2	21.2	21.1	20.9	20.5	20.0	19.2
10	21.3	21.0	20.9	20.7	20.5	20.2	19.5	18.7
20	20.9	20.6	20.5	20.4	20.2	19.8	19.1	18.3
40	20.4	20.1	20.1	20.0	19.8	19.4	18.8	18.0
80	19.8	19.5	19.5	19.4	19.2	18.8	18.2	17.5
160	19.3	19.0	19.0	18.9	18.7	18.4	17.8	17.0
320	18.8	18.5	18.5	18.4	18.3	17.9	17.3	16.5
640	18.3	18.1	18.1	18.0	17.8	17.5	16.8	16.0

V_{REF}=1.65V, f_{ADCK}=409kHz

Data Rate (SPS)	PGA Gain							
	1	2	4	8	16	32	64	128
12.5	21.8	21.4	21.2	21.1	20.7	20.3	19.5	18.6
25	21.4	21.1	20.9	20.7	20.3	19.7	19.0	18.2
50	20.9	20.6	20.5	20.3	19.9	19.4	18.6	17.7
100	20.4	20.2	20.0	19.8	19.4	18.9	18.1	17.3
200	19.8	19.4	19.3	19.2	18.9	18.4	17.7	16.8
400	19.0	18.8	18.7	18.6	18.4	17.8	17.2	16.3
800	18.7	18.4	18.3	18.2	17.9	17.4	16.7	15.8
1600	18.2	18.0	17.9	17.7	17.3	16.7	16.2	15.4

V_{REF}=1.2V, f_{ADCK}=163kHz

Data Rate (SPS)	PGA Gain							
	1	2	4	8	16	32	64	128
5	20.6	20.4	20.4	20.3	20.3	20.1	19.6	18.9
10	20.5	20.3	20.3	20.2	20.0	19.9	19.2	18.4
20	20.3	19.9	19.9	19.8	19.7	19.4	18.8	18.0
40	19.8	19.5	19.5	19.4	19.2	18.9	18.3	17.5
80	19.3	19.1	19.1	19.0	18.8	18.5	17.8	17.0
160	19.0	18.8	18.7	18.6	18.3	18.0	17.4	16.5
320	18.5	18.2	18.2	18.1	17.8	17.5	16.9	16.1
640	17.9	17.7	17.7	17.6	17.3	17.0	16.4	15.6

V_{REF}=1.2V, f_{ADCK}=409kHz

Data Rate (SPS)	PGA Gain							
	1	2	4	8	16	32	64	128
12.5	20.9	20.7	20.5	20.3	20.1	19.8	19.1	18.2
25	20.7	20.4	20.2	20.1	19.8	19.4	18.6	17.8
50	20.3	20.1	19.8	19.7	19.4	18.8	18.1	17.4
100	19.9	19.6	19.4	19.2	18.9	18.4	17.7	16.8
200	19.5	19.2	19.0	18.8	18.5	17.9	17.2	16.4
400	18.9	18.7	18.6	18.4	18.0	17.5	16.7	15.9
800	18.5	18.2	18.0	17.8	17.5	16.9	16.2	15.4
1600	17.9	17.6	17.5	17.3	16.9	16.4	15.7	14.9

Internal Reference Voltage Characteristics

Table 22. Internal Reference Voltage Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_{DDA}	Operating Voltage	—		1.65	—	3.6	V
V_{REF}	Internal Reference Voltage after Factory Trimming at 25 ˚C Temperature	V_{DDA} ≥ 1.65 V	VREFSEL[1:0] = 00	1.190	1.215	1.240	V
		V_{DDA} ≥ 2.30 V	VREFSEL[1:0] = 01	1.96	2.00	2.04	
		V_{DDA} ≥ 2.80 V	VREFSEL[1:0] = 10	2.45	2.50	2.55	
		V_{DDA} ≥ 3.00 V	VREFSEL[1:0] = 11	2.65	2.70	2.75	
ACC_{VREF}	Reference Voltage Accuracy after Trimming	V_{DDA} = 1.65 V ~ 3.6 V, V_{REF} = 1.215 V, T_A = -40 °C ~ 85 °C		-3.0	—	+3.0	%
t_{STABLE}	Reference Voltage Stable Time	—		—	—	100	ms
t_{SREFV}	ADC Sampling Time when Reading Reference Voltage	—		10	—	—	μs
I_{DD}	Operating Current	—		—	45	55	μA
I_{DDPWD}	Reference Voltage Power Down Current	—		—	—	0.01	μA

V_{DDA} Monitor Characteristics

Table 23. V_{DDA} Monitor Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
R	Resistor Bridge for V_{DDA}		—	50	—	kΩ
Q	Ratio on V_{DDA} Measurement		—	2	—	—
E_R	Error on Ratio		-1	—	+1	%
t_{SVDDA}	ADC Sampling Time when Reading the V_{DDA}		5	—	—	μs

Note: Guaranteed by design, not tested in production.

GPTM/PWM Characteristics

Table 24. GPTM/PWM Characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
f_{TM}	Timer Clock Source for GPTM, PWM	—	—	—	f_{PCLK}	MHz
t_{RES}	Timer Resolution Time	—	1	—	—	$1/f_{TM}$
f_{EXT}	External Signal Frequency on Channel 1 ~ 4	—	—	—	1/2	f_{TM}
RES	Timer Resolution	—	—	—	16	bits

I^2C Characteristics

Table 25. I^2C Characteristics

Symbol	Parameter	Standard Mode		Fast Mode		Fast Plus Mode		Unit
		Min.	Max.	Min.	Max.	Min.	Max.	
f_{SCL}	SCL Clock Frequency	—	100	—	400	—	1000	kHz
$t_{SCL(H)}$	SCL Clock High Time	4.5	—	1.125	—	0.45	—	μs
$t_{SCL(L)}$	SCL Clock Low Time	4.5	—	1.125	—	0.45	—	μs
t_{FALL}	SCL and SDA Fall Time	—	1.3	—	0.34	—	0.135	μs
t_{RISE}	SCL and SDA Rise Time	—	1.3	—	0.34	—	0.135	μs
$t_{SU(SDA)}$	SDA Data Setup Time	500	—	125	—	50	—	ns
$t_{H(SDA)}$	SDA Data Hold Time	0	—	0	—	0	—	ns
$t_{SU(STA)}$	START Condition Setup Time	500	—	125	—	50	—	ns
$t_{H(STA)}$	START Condition Hold Time	0	—	0	—	0	—	ns
$t_{SU(STO)}$	STOP Condition Setup Time	500	—	125	—	50	—	ns

Note: 1.Guaranteed by design, 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 mode plus, the peripheral clock frequency must be higher than 20 MHz.
5. The above characteristic parameters of the I^2C bus timing are based on: SEQFILTER = 01 and COMBFILTEREN = 0 that COMB_filter is disabled.

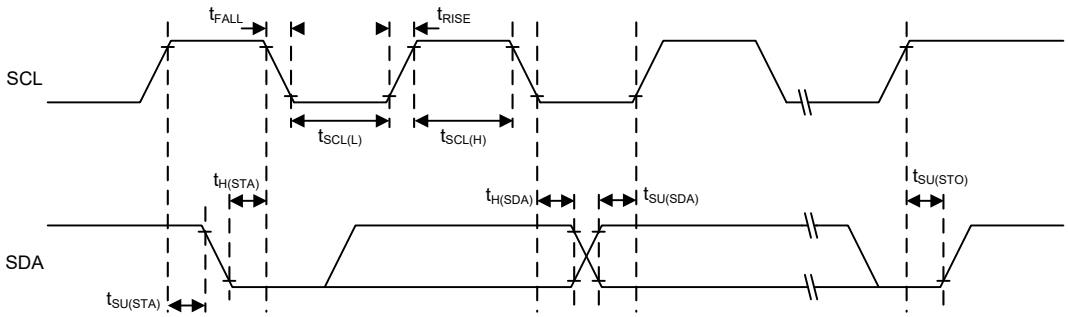


Figure 8. I²C Timing Diagram

SPI Characteristics

Table 26. SPI Characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
SPI Master Mode						
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
SPI Slave Mode						
f_{SCK}	SPI Slave Input SCK Clock Frequency	Slave mode, SPI peripheral clock frequency f_{PCLK}	—	—	$f_{PCLK}/3$	MHz
$Duty_{SCK}$	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 $t_{PCLK} = 1/f_{PCLK}$.

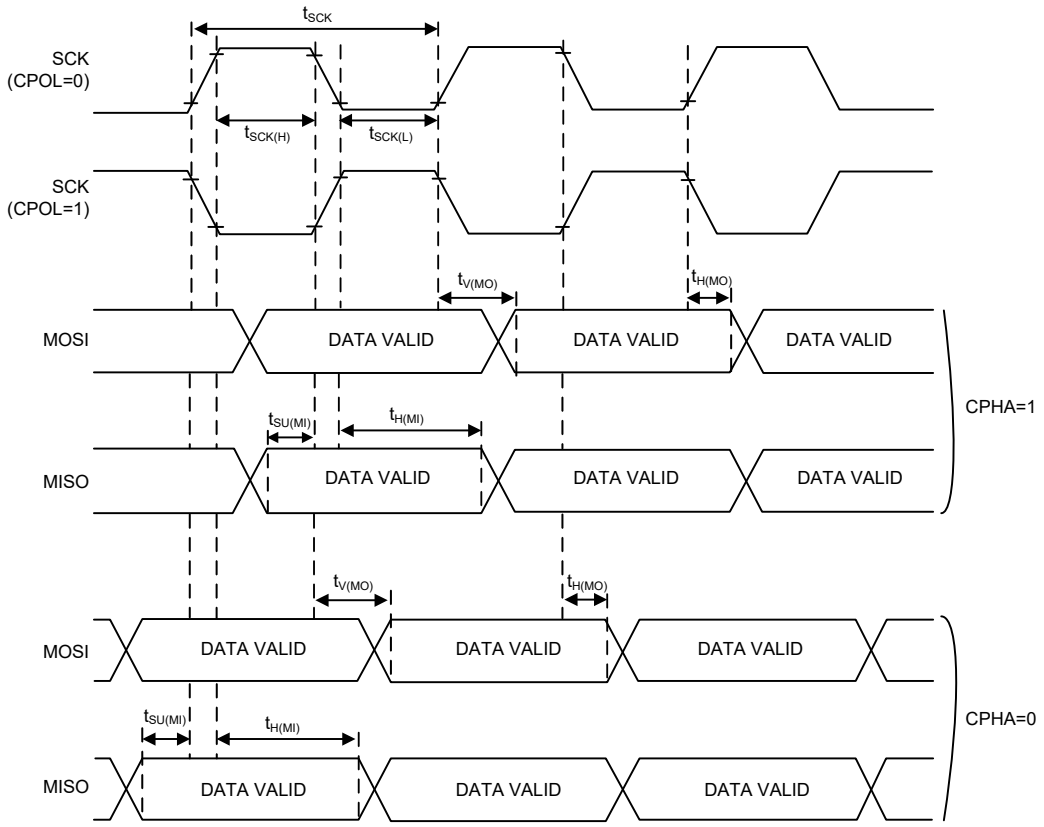


Figure 9. SPI Timing Diagram – SPI Master Mode

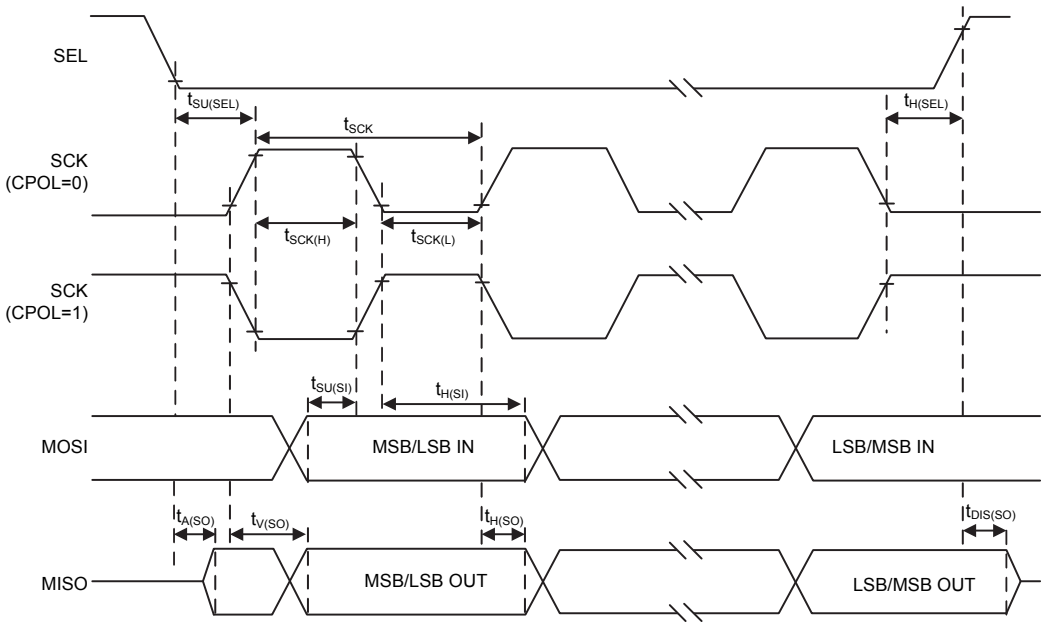


Figure 10. SPI Timing Diagram – SPI Slave Mode with CPHA = 1

LCD Characteristics

Table 27. LCD Characteristics

T_A = 25 °C, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{LCD}	LCD External Voltage	—	—	—	3.6	V
	LCD Internal Charge Pump Voltage	—	—	2.65	—	V
		—	—	2.75	—	V
		—	—	2.85	—	V
		—	—	2.95	—	V
		—	—	3.1	—	V
		—	—	3.25	—	V
		—	—	3.4	—	V
		—	—	3.55	3.6	V
C_{LCD}	V_{LCD} External Capacitor	—	0.22	—	2.2	μF
I_{LCD}	Supply Current @ V_{DD} = 3.3 V	External V_{LCD}(1)	—	2.4	—	μA
	Supply Current @ V_{DD} = 2.7 V	Internal charge pump(2)	—	50	—	
R_H	Internal Low Drive Resister Network Overall Value	—	—	3	—	MΩ
R_L	Internal High Drive Resister Network Overall Value	—	—	120	—	kΩ
V_{44}	Segment/Common Highest Level Voltage	—	—	—	V_{LCD}	V
V_{34}	Segment/Common 3/4 Level Voltage	—	—	3/4 V_{LCD}	—	V
V_{23}	Segment/Common 2/3 Level Voltage	—	—	2/3 V_{LCD}	—	V
V_{12}	Segment/Common 1/2 Level Voltage	—	—	1/2 V_{LCD}	—	V
V_{13}	Segment/Common 1/3 Level Voltage	—	—	1/3 V_{LCD}	—	V
V_{14}	Segment/Common 1/4 Level Voltage	—	—	1/4 V_{LCD}	—	V
V_0	Segment/Common Lowest Level Voltage	—	0	—	—	V

Note: 1. LCD enabled with external V_{LCD} = V_{DD} = 3.3 V, 1/4 duty, 1/3 bias, division ratio = 64, high drive disabled, all pixels active, no LCD connected.

2. LCD enabled with internal charge pump V_{LCD} = 3.25 V, V_{DD} = 2.7 V, 1/4 duty, 1/3 bias, division ratio = 64, high drive disabled, all pixels active, no LCD connected.

3. Guaranteed by design, not tested in production.

USB Characteristics

The USB interface is USB-IF certified - Full Speed.

Table 28. USB DC Electrical Characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{DD}	USB Operating Voltage	—	3.0	—	3.6	V
V_{DI}	Differential Input Sensitivity	|USBDP-USBDM|	0.2	—	—	V
V_{CM}	Common Mode Voltage Range	—	0.8	—	2.5	V
V_{SE}	Single-ended Receiver Threshold	—	0.8	—	2.0	V
V_{OL}	Pad Output Low Voltage	1.5 kΩ R_L to V_{DD33}	0	—	0.3	V
V_{OH}	Pad Output High Voltage		2.8	—	3.6	V
V_{CRS}	Differential Output Signal Cross-point Voltage		1.3	—	2.0	V
Z_{DRV}	Driver Output Resistance	—	—	10	—	Ω
C_{IN}	Transceiver Pad Capacitance	—	—	—	20	pF

Note: 1. Guaranteed by design, not tested in production.
2. The USB functionality is ensured down to 2.7 V but not for the full USB electrical characteristics which will experience degradation in the V_{DD} voltage range of 2.7 to 3.0 V.
3. R_L is the resistor load connected to the USB driver USBDP.

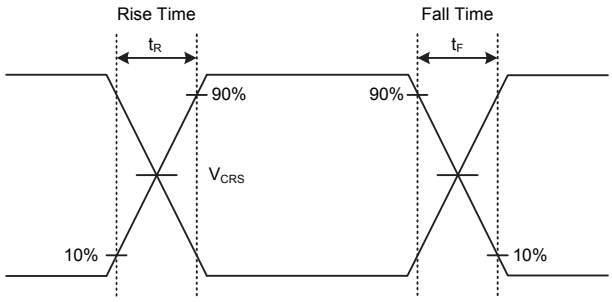


Figure 11. USB Signal Rise Time and Fall Time and Cross-Point Voltage (V_{CRS}) Definition

Table 29. USB AC Electrical Characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
t_R	Rise Time	C_L = 50 pF	4	—	20	ns
t_F	Fall Time	C_L = 50 pF	4	—	20	ns
$t_{R/F}$	Rise Time / Fall Time Matching	$t_{R/F} = t_R / t_F$	90	—	110	%

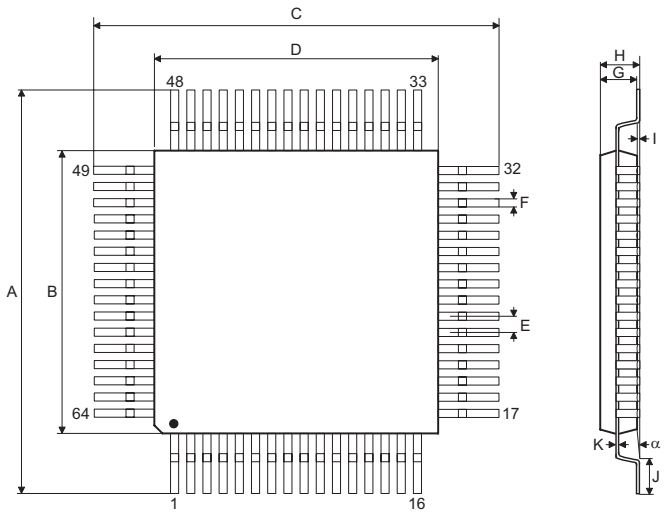
7 Package Information

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

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

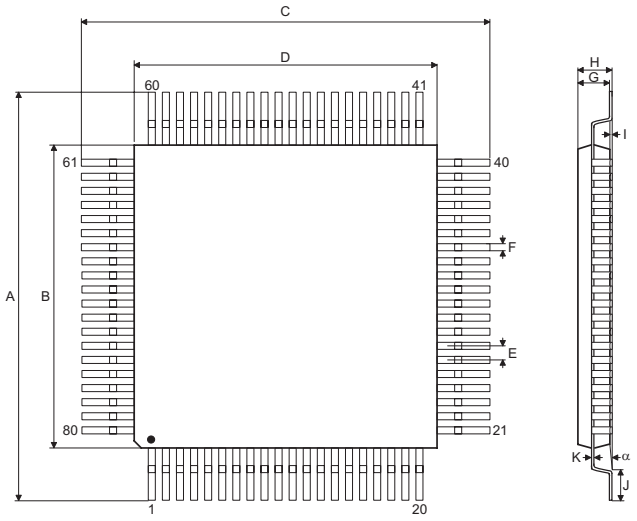
64-pin LQFP (7mm × 7mm) Outline Dimensions



Symbol	Dimensions in inch		
	Min.	Nom.	Max.
A	—	0.354 BSC	—
B	—	0.276 BSC	—
C	—	0.354 BSC	—
D	—	0.276 BSC	—
E	—	0.016 BSC	—
F	0.005	0.007	0.009
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
α	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	—	0.40 BSC	—
F	0.13	0.18	0.23
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
α	0°	—	7°

80-pin LQFP (10mm × 10mm) Outline Dimensions



Symbol	Dimensions in inch		
	Min.	Nom.	Max.
A	—	0.472 BSC	—
B	—	0.394 BSC	—
C	—	0.472 BSC	—
D	—	0.394 BSC	—
E	—	0.016 BSC	—
F	0.005	0.007	0.009
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
α	0°	—	7°

Symbol	Dimensions in mm		
	Min.	Nom.	Max.
A	—	12 BSC	—
B	—	10 BSC	—
C	—	12 BSC	—
D	—	10 BSC	—
E	—	0.4 BSC	—
F	0.13	0.18	0.23
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
α	0°	—	7°