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STM32WBA6xxx

life.augmented

Multiprotocol wireless 32-bit MCU Arm®-based Cortex®-M33 with TrustZone®, FPU, Bluetooth® IEEE802.15.4 radio solution

Datasheet - preliminary data

Features

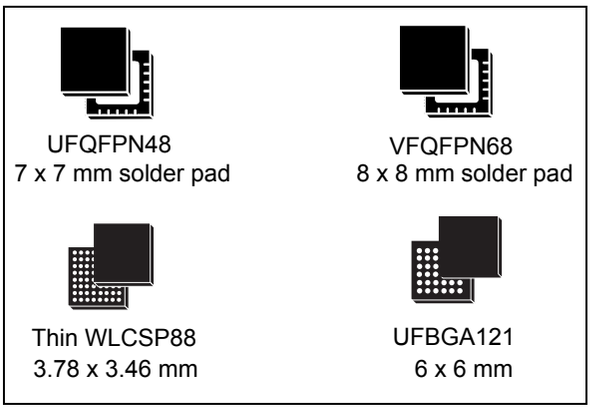
Includes ST state-of-the-art patented technology

Ultra-low-power radio

- 2.4 GHz radio
- RF transceiver supporting Bluetooth® Low Energy 5.4 specification, IEEE 802.15.4-2015 PHY and MAC, supporting Thread, Matter, and Zigbee®
- Proprietary protocols
- RX sensitivity: -96 dBm (Bluetooth® Low Energy at 1 Mbps), -100 dBm (IEEE 802.15.4 at 250 kbps)
- Programmable output power up to +10 dBm, with 1 dB steps
- Support for external PA
- Isochronous channel (Auracast/Unicast), AOA/AOD, long range
- Packet traffic arbitration
- Integrated balun to reduce BOM
- Single crystal operation
- Suitable for systems requiring compliance with radio frequency regulations ETSI EN 300 328, EN 300 440, FCC CFR47 Part 15 and ARIB STD-T66

Ultra-low-power with FlexPowerControl

- 1.71 to 3.6 V power supply
- -40 to 85/105 °C ambient temperature range
- Autonomous peripherals with DMA, functional down to Stop 1 mode
- 120 nA Standby mode (16 wake-up pins)
- 1.33 µA Standby mode with RTC



- 1.15 µA Standby mode with 64-Kbyte SRAM
- 5.30 µA Stop 2 mode with 64-Kbyte SRAM
- 29 µA/MHz Run mode
- Radio: Rx 4.26 mA / Tx at 0 dBm 5.94 mA

Core

- Arm® 32-bit Cortex®-M33 CPU with TrustZone®, MPU, DSP, and FPU

ART Accelerator

- 8-Kbyte instruction cache allowing 0-wait-state execution from flash memory (frequency up to 100 MHz, 150 DMIPS)

Benchmarks

- 1.5 DMIPS/MHz (Dhrystone 2.1)
- 410 CoreMark® (4.10 CoreMark/MHz)

Memories

- Up to 2-Mbyte dual bank flash memory with ECC, including 512 Kbytes with 100 K cycles
- Up to 512-Kbyte SRAM, including 64 Kbytes with parity check
- 512-byte (32 rows) OTP

This is preliminary information on a new product now in development or undergoing evaluation. Details are subject to change without notice.

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Power management

- Embedded regulator LDO and SMPS step-down converter, supporting switch on-the-fly and voltage scaling

Clock management

- 32 MHz crystal oscillator
- 32 kHz crystal oscillator (LSE)
- Internal low power 32 kHz (±5%) RC
- Internal low frequency 32 kHz RC (500 ppm/°C)
- Internal 16 MHz factory trimmed RC (±1%)
- PLL for system clock, audio, and ADC

General-purpose input/output

- Up to 86 I/Os (most of them 5 V-tolerant) with interrupt capability, and up to 14 I/Os with independent supply down to 1.08 V

Analog peripherals (independent supply)

- 12-bit ADC 2.5 Msps, up to 16-bit with hardware oversampling
- Two ultra-low-power comparators

Communication peripherals

- One USB OTG high-speed with embedded PHY
- One SAI (serial audio interface)
- Four UARTs (ISO 7816, IrDA, modem)
- Three SPIs
- Four I2Cs FM+ (1 Mbit/s), SMBus/PMBus®

System peripherals

- Touch sensing controller, up to 24 sensors, supporting touch key, linear, and rotary touch sensors
- One 16-bit, advanced motor control timer
- Three 16-bit timers and two 32-bit timers
- Two low power 16-bit timers (available in Stop mode)
- Two Systick timers
- RTC with hardware calendar and calibration
- Two watchdogs
- 8-channel DMA controller, functional in Stop mode

Security and cryptography

- Arm® TrustZone® and securable I/Os, memories, and peripherals
- Flexible life cycle scheme with read-out protection (RDP) and password protected debug
- Root of trust thanks to unique boot entry and secure hide protection area (HDP)
- Secure firmware installation (SFI), thanks to embedded root secure services (RSS)
- Secure data storage with hardware unique key (HUK)
- Secure firmware upgrade support with TF-M
- Two AES coprocessors, including one with DPA resistance
- Public key accelerator, DPA resistant
- HASH hardware accelerator
- True random number generator, NIST SP800-90B compliant
- 96-bit unique ID
- Active tampers
- CRC calculation unit

Development support

- Serial wire debug (SWD), JTAG
- Embedded trace (ETM)

ECOPACK2 compliant packages

Table 1. Device summary

Reference	Part numbers
STM32WBA62xx	STM32WBA62CG, STM32WBA62CI, STM32WBA62MG, STM32WBA62MI, STM32WBA62PG, STM32WBA62PI
STM32WBA63xx	STM32WBA63CG, STM32WBA63CI
STM32WBA64xx	STM32WBA64CG, STM32WBA64CI
STM32WBA65xx	STM32WBA65CG, STM32WBA65CI, STM32WBA65MG, STM32WBA65MI, STM32WBA65PG, STM32WBA65PI, STM32WBA65RG, STM32WBA65RI

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1 Introduction

This document provides the ordering information and mechanical device characteristics of the STM32WBA6xxx microcontrollers, based on Arm® cores[a]. It must be read in conjunction with the reference manual (RM0515), available from the STMicroelectronics website *www.st.com*.

For information on the device errata with respect to the datasheet and reference manual refer to the STM32WBA6xxx errata sheet (ES0644), available from the STMicroelectronics website *www.st.com*.

For information on the Arm® Cortex®-M33 core, refer to the Cortex®-M33 Technical Reference Manual, available on the www.arm.com website.

For information on 802.15.4, refer to the IEEE website (www.ieee.org).

For information on Bluetooth®, refer to www.bluetooth.com.

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2 Description

The STM32WBA6xxx multiprotocol wireless and ultra-low-power devices embed a powerful and ultra-low-power radio compliant with the Bluetooth® SIG Low Energy specification 5.4 and with IEEE 802.15.4-2015. They contain a high-performance Arm® Cortex®-M33 32-bit RISC core, and operate at a frequency of up to 100 MHz.

The devices integrate a 2.4 GHz RADIO supporting Bluetooth Low Energy, Matter, Thread, and Zigbee®, and make possible to use proprietary protocols and concurrent operation modes. They provide support for an array of up to eight antennas, and an external power amplifier. PTA (packet traffic arbitration) interface is supported as well.

The Cortex-M33 core features a single-precision floating-point unit (FPU), supporting all the Arm single-precision data-processing instructions and all the data types. This core implements a full set of DSP (digital signal processing) instructions and a memory protection unit (MPU) that enhances the application security.

The devices embed high-speed memories (up to 2-Mbyte flash, up to 512-Kbyte SRAM), an extensive range of enhanced I/Os, and peripherals connected to AHB and APB buses on the 32-bit multi-AHB bus matrix.

The security foundation is compliant with the TBSA (trusted-based security architecture) requirements from Arm. It embeds the features needed to implement secure boot, secure data storage, and secure firmware update. Besides these capabilities, the devices incorporate a secure firmware installation feature that allows the customer to secure the provisioning of the code during its production. A flexible life cycle is managed thanks to multiple levels readout protection and debug unlock with password.

Firmware hardware isolation is supported thanks to securable peripherals, memories and I/Os, and privilege configuration of peripherals and memories.

The devices feature protection mechanisms for embedded flash memory and SRAM: readout protection, write protection, secure, and hide protection areas.

Dedicated peripherals reinforce security: a fast AES coprocessor, a secure AES coprocessor with DPA resistance and hardware unique key that can be shared by hardware with fast AES, a PKA (public key accelerator) with DPA resistance, a HASH hardware accelerator, and a true random number generator.

The devices offer active tamper detection and protection against transient perturbation attacks, thanks to several internal monitoring generating secret data erase in case of attack. This helps to fit the PCI requirements for point of sales applications.

Hardware semaphores allow synchronization between software processes.

The devices offer one 12-bit ADC (2.5 Msps), up to two comparators, a low-power RTC, up to two 32-bit general-purpose timer, one 16-bit PWM timer for motor control, three 16-bit general-purpose timers, and two 16-bit low-power timers. They also feature standard and advanced communication interfaces, namely up to four I2Cs, up to three SPIs, one SAI, up to three USARTs, one low-power UART, and one USB OTG high-speed.

The devices operate in the -40 to 85 °C (105 °C junction) and -40 to 105 °C (125 °C junction) temperature ranges from a 1.71 to 3.6 V power supply.

The design of low-power applications is enabled by a comprehensive set of power-saving modes.

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Many peripherals (including radio, communication, analog, and timer peripherals) can be functional and autonomous in Stop mode with direct memory access thanks to background autonomous mode (BAM) support.

Some independent power supplies are supported, like an analog independent supply input for ADC and comparators, USB OTG high-speed, 14 GPIOs and dedicated supply inputs for the 2.4 GHz RADIO.

The devices offer four packages, from 48 to 121 pins, with or without SMPS.

Table 2. Device features and peripheral counts

Feature		STM32WBA62CI	STM32WBA62CG	STM32WBA63CI	STM32WBA63CG	STM32WBA64CI	STM32WBA64CG	STM32WBA65CI	STM32WBA65CG	STM32WBA65RI	STM32WBA65RG	STM32WBA62PI	STM32WBA62PG	STM32WBA65PI	STM32WBA65PG	STM32WBA62MI	STM32WBA62MG	STM32WBA65MI	STM32WBA65MG
Flash memory density (Mbytes)		2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
SRAM density	SRAM1 (Kbytes)	448	192	448	192	448	192	448	192	448	192	448	192	448	192	448	192	448	192
	SRAM2 (Kbytes)	64																	
Bluetooth Low Energy		Yes																	
IEEE802.15.4		No		Yes								No		Yes		No		Yes	
SMPS		No		Yes		No		Yes				No		Yes		No		Yes	
PTA		Yes																	
External PA support		No		Yes								No		Yes		No		Yes	
BLE AoA, AoD support		No		Yes								No		Yes		No		Yes	
Timers	Advanced control (16-bit)	1																	
	General purpose (32-bit)	2		1		2													
	General purpose (16-bit)	3																	
	Low power (16-bit)	2																	
	SysTick	2																	
Communication interfaces	SPI	2								3									
	I2C	4		2		4		2		4									
	USART	3		2		3													
	LPUART	1																	
	SAI	1																	
	USB OTG high-speed	Yes		No		Yes													
	IRTIM	No		Yes		No				Yes									
RTC		Yes																	
Tamper pins (active tampers)(1)		4 (3)		5 (4)		4 (3)						6 (5)							
Wake-up pins		11		14		11		10		14		16							
GPIOs		34		31		34		30		46		86				54			
TSC (capacitive sensing channels)		10		12		10		7		16		24				19			
12-bit ADC4 (channels)		7		8		7		6		10									
Comparators		1		2		1				2									
VREF		No								Yes									

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Table 2. Device features and peripheral counts (continued)

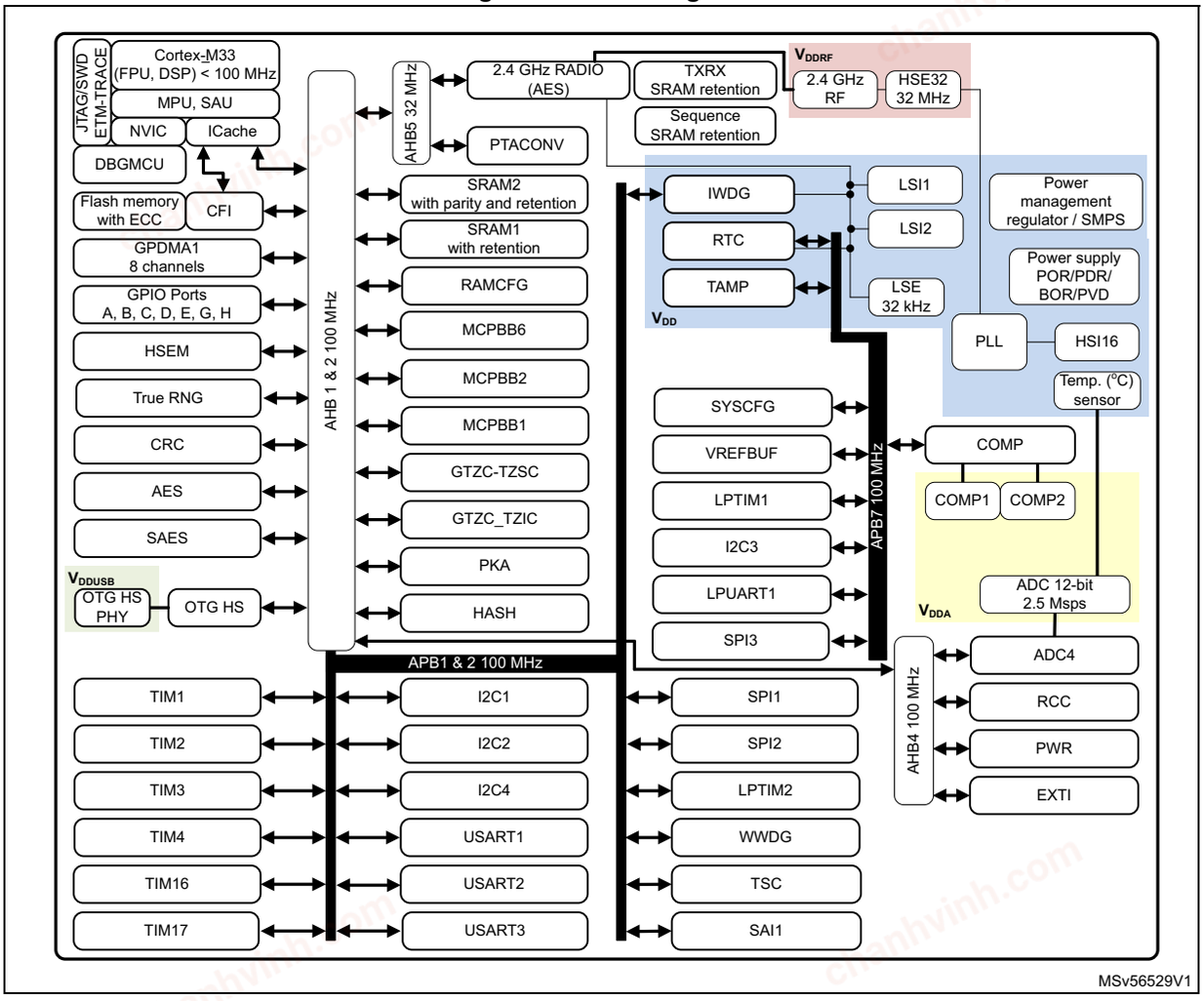
Feature	STM32WBA62CI	STM32WBA62CG	STM32WBA63CI	STM32WBA63CG	STM32WBA64CI	STM32WBA64CG	STM32WBA65CI	STM32WBA65CG	STM32WBA65RI	STM32WBA65RG	STM32WBA62PI	STM32WBA62PG	STM32WBA65PI	STM32WBA65PG	STM32WBA62MI	STM32WBA62MG	STM32WBA65MI	STM32WBA65MG
True random number generator	Yes																	
SAES, AES	Yes																	
Public key accelerator (PKA)	Yes																	
HASH	Yes																	
Debug ETM	No								Yes									
Maximum CPU frequency	100 MHz																	
Operating temperature	Ambient: -40 to 85 °C / -40 to 105 °C Junction: -40 to 105 °C / -40 to 125 °C																	
Operating voltage	1.71 to 3.6 V																	
Package	UFQFPN48								VFQ FPN68		UFBGA121				Thin WLCSP88			

1. Active tampers in output sharing mode (one output shared by all inputs).

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Figure 1 shows the general block diagram of the devices.

Figure 1. Block diagram



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3 Functional overview

3.1 Arm Cortex-M33 core with TrustZone, MPU, DSP, and FPU

The Cortex-M33 with TrustZone, MPU, DSP and FPU is a highly energy-efficient processor designed for microcontrollers and deeply embedded applications, especially those requiring efficient security.

The Cortex-M33 processor delivers a high computational performance with low-power consumption and an advanced response to interrupts. It features:

- Arm TrustZone technology, using the Armv8-M main extension supporting secure and nonsecure states
- MPUs (memory protection units), supporting up to 16 regions for secure and nonsecure applications
- Configurable SAU (secure attribute unit) supporting up to eight memory regions as secure or nonsecure
- Floating-point arithmetic functionality with support for single precision arithmetic

The processor supports a set of DSP instructions that allows an efficient signal processing and a complex algorithm execution.

The Cortex-M33 processor supports the following bus interfaces:

- System AHB (S-AHB) bus: used for any instruction fetch and data access to the memory-mapped SRAM, peripheral, and Vendor_SYS regions of the Armv8-M memory map.
- Code AHB (C-AHB) bus: used for any instruction fetch and data access to the code region of the Armv8-M memory map.

3.2 ART Accelerator (ICACHE)

The ICACHE (instruction cache) is introduced on C-AHB code bus of Cortex-M33 processor to improve performance when fetching instruction (or data) from internal memories.

ICACHE offers the following features:

- Multibus interface:
  - Slave port receiving the memory requests from the Cortex-M33 C-AHB code execution port
  - Master1 port performing refill requests to internal flash memory
  - Master2 port performing refill requests to internal SRAM memories
  - Second slave port dedicated to ICACHE registers access

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- Close to 0 wait-states instructions/data access performance:
  - 0 wait-states on cache hit
  - Hit-under-miss capability, allowing to serve new processor requests while a line refill (due to a previous cache miss) is still ongoing
  - Critical-word-first refill policy, minimizing processor stalls on cache miss
  - Hit ratio improved by two-ways set-associative architecture and pLRU-t replacement policy (pseudo-least-recently-used, based on binary tree), algorithm with best complexity/performance balance
  - Dual master ports to decouple internal flash memory and SRAM traffic, on fast and slow buses, respectively; also minimizing impact on interrupt latency
  - Optimal cache line refill thanks to AHB burst transactions (of the cache line size)
  - Performance monitoring by means of a hit counter and a miss counter
- Extension of cacheable region beyond the code memory space, by means of address remapping logic enabling the definition of four cacheable regions
- Power consumption reduced intrinsically (more accesses to cache memory rather to bigger main memories); even improved by configuring ICACHE as direct mapped (rather than the default two-ways set-associative mode)
- TrustZone security support
- Maintenance operation for software management of cache coherency
- Error management: detection of unexpected cacheable write access, with optional interrupt raising

3.3 Memory protection unit

The MPU is used to manage the CPU accesses to the memory and to prevent one task to accidentally corrupt the memory or the resources used by any other active task. This memory area is organized into up to 16 protected areas. The MPU regions and registers are banked across secure and nonsecure states.

The MPU is especially helpful for applications where some critical or certified code must be protected against the misbehavior of other tasks. It is usually managed by an RTOS (real-time operating system).

If a program accesses a memory location prohibited by the MPU, the RTOS can detect it and take action. In an RTOS environment, the kernel can dynamically update the MPU area setting based on the process to be executed.

The MPU is optional and can be bypassed for applications that do not need it.

3.4 Multi-AHB bus matrix

A 32-bit multi-AHB bus matrix interconnects all the masters (CPU, GPDMA1, USB OTG) and the slaves (flash memory, SRAMs, AHB, and APB) peripherals. It also ensures a seamless and efficient operation even when several peripherals work simultaneously.

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3.5 Embedded flash memory

The devices feature an up to 2-Mbyte embedded flash memory, available to store programs and data. This memory supports 10000 cycles, and up to 100000 cycles on 64 pages (512 Kbytes).

A 128-bit instruction prefetch is implemented and can optionally be enabled.

The flash memory interface features dual-bank operation modes and read-while-write (RWW), hence a read operation to be performed from one bank while an erase or program operation is performed on the other bank. The dual-bank boot is also supported. Each bank contains up to 128 pages of 8 Kbytes. The flash memory also embeds a 512-byte one-time programmable (OTP) memory for user data.

The whole nonvolatile memory embeds the error correction code (ECC) feature supporting:

- single-error detection and correction
- double-error detection
- ECC fail address report

3.5.1 Flash memory protections

The user options allow the configuration of flexible protections:

- write protection (WRP) to protect areas against erasing and programming. Two areas per bank can be selected with 8-Kbyte granularity
- readout protection (RDP) to protect the whole memory, has four levels of protection available (see *Table 3* and *Table 4*):
  - Level 0: no readout protection
  - Level 0.5: available only when TrustZone is enabled

    All read/write operations (if no write protection is set) from/to the nonsecure flash memory are possible. The debug access to secure area is prohibited. Debug access to nonsecure area remains possible.
  - Level 1: memory readout protection

    The flash memory cannot be read from or written to if either the debug features are connected or the boot in RAM or bootloader are selected. If TrustZone is enabled, the nonsecure debug is possible and the boot in SRAM is not possible. Regressions from Level 1 to lower levels can be protected by password authentication.
  - Level 2: chip readout protection

    The debug features, the boot in RAM and the bootloader selection are disabled. A secure secret key can be configured in the secure options to allow the regression capability from Level 2 to Level 1. By default (key not configured), this Level 2 selection is irreversible and JTAG/SWD interfaces are disabled. If the secret key was previously configured in lower RDP levels, the device enables the RDP regression from Level 2 to Level 1 after password authentication through JTAG/SWD interface.

Note: To reach the best protection level, it is recommended to activate TrustZone and to set RDP level 2 with password authentication regression enabled.

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Table 3. Access status versus protection level and execution modes when TZEN = 0

Area	RDP level	User execution (boot from flash memory)			Debug/boot from RAM/ bootloader(1)		
		Read	Write	Erase	Read	Write	Erase
Flash main memory	1	Yes	Yes	Yes	No	No	No(4)
	2	Yes	Yes	Yes	N/A	N/A	N/A
System memory(2)	1	Yes	No	No	Yes	No	No
	2	Yes	No	No	N/A	N/A	N/A
Option bytes(3)	1	Yes	Yes(4)	N/A	Yes	Yes(4)	N/A
	2	Yes	No(5)	N/A	N/A	N/A	N/A
OTP	1	Yes	Yes(6)	N/A	Yes	Yes(6)	N/A
	2	Yes	Yes(6)	N/A	N/A	N/A	N/A
Backup registers	1	Yes	Yes	N/A	No	No	N/A(7)
	2	Yes	Yes	N/A	N/A	N/A	N/A
SRAM2	1	Yes	Yes	N/A	No	No	N/A(8)
	2	Yes	Yes	N/A	N/A	N/A	N/A

1. When the protection level 2 is active, the debug port, the boot from RAM, and the boot from system memory are disabled.
2. The system memory is only read-accessible, whatever the protection level (0, 1 or 2) and execution mode.
3. Option bytes are accessible only through the flash memory interface registers and OPSTRT bit.
4. The flash main memory is erased when the RDP option byte changes from level 1 to level 0.
5. SWAP_BANK user option can be modified.
6. OTP can be written only once.
7. The backup registers are erased when RDP changes from level 1 to level 0.
8. All SRAMs are erased when RDP changes from level 1 to level 0.

Table 4. Access status versus protection level and execution modes when TZEN = 1

Area	RDP level	User execution (boot from flash memory)			Debug/bootloader(1)		
		Read	Write	Erase	Read	Write	Erase
Flash main memory	0.5	Yes	Yes	Yes	Yes(2)	Yes(2)	Yes(2)
	1	Yes	Yes	Yes	No	No	No(5)
	2	Yes	Yes	Yes	N/A	N/A	N/A
System memory(3)	0.5	Yes	No	No	Yes	No	No
	1	Yes	No	No	Yes	No	No
	2	Yes	No	No	N/A	N/A	N/A
Option bytes(4)	0.5	Yes	Yes(5)	N/A	Yes	Yes (5)	N/A
	1	Yes	Yes(5)	N/A	Yes	Yes(5)	N/A
	2	Yes	No(6)	N/A	N/A	N/A	N/A

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Table 4. Access status versus protection level and execution modes when TZEN = 1 (continued)

Area	RDP level	User execution (boot from flash memory)			Debug/bootloader(1)		
		Read	Write	Erase	Read	Write	Erase
OTP	0.5	Yes	Yes(7)	N/A	Yes	Yes(7)	N/A
	1	Yes	Yes(7)	N/A	Yes	Yes(7)	N/A
	2	Yes	Yes(7)	N/A	N/A	N/A	N/A
Backup registers	0.5	Yes	Yes	N/A	Yes(2)	Yes(2)	N/A(8)
	1	Yes	Yes	N/A	No	No	N/A(8)
	2	Yes	Yes	N/A	N/A	N/A	N/A
SRAM2	0.5	Yes	Yes	N/A	Yes(2)	Yes(2)	N/A(9)
	1	Yes	Yes	N/A	No	No	N/A(9)
	2	Yes	Yes	N/A	N/A	N/A	N/A

1. When the protection level 2 is active, the debug port and the bootloader mode are disabled.
2. Depends on TrustZone security access rights.
3. The system memory is only read-accessible, whatever the protection level (0, 1 or 2) and execution mode.
4. Option bytes are only accessible through the flash registers interface and OPSTRT bit.
5. The flash main memory is erased when the RDP option byte regresses from level 1 to level 0.
6. SWAP_BANK user option can be modified.
7. OTP can be written only once.
8. The backup registers are erased when RDP changes from level 1 to level 0.
9. All SRAMs are erased when RDP changes from level 1 to level 0.

3.5.2 Additional flash memory protections when TrustZone is activated

When the TrustZone security is enabled through option bytes, the whole flash memory is secure after reset and the following protections are available:

- Nonvolatile watermark-based secure flash memory area

  The secure area can be accessed only in Secure mode. One area can be selected with a page granularity.
- Secure hide protection area (HDP)

  It is part of the flash memory secure area and can be protected to deny access to this area by any data read, write, and instruction fetch. For example, a software code in the secure flash memory hide protection area can be executed only once and deny any further access to this area until the next system reset. One area can be selected at the beginning of the secure area.
- Volatile block-based secure flash memory area

  Each page can be programmed on-the-fly as secure or nonsecure.

3.5.3 FLASH privilege protection

Each flash memory page can be programmed on-the-fly as privileged or unprivileged.

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3.6 Embedded SRAMs

SRAM1 and SRAM2 are the main embedded SRAMs, each with specific features. These memories can be used for peripherals background autonomous mode (BAM).

The SRAMs can be powered down in Stop mode to reduce consumption:

- SRAM1: up to seven 64-Kbyte blocks (up to 448 Kbytes), can be retained in Standby mode
- SRAM2: one 64-Kbyte block with parity, can be retained in Standby mode.

3.6.1 SRAMs TrustZone security

When TrustZone security is enabled, SRAMs are secure after reset. SRAM1 and SRAM2 can be programmed as secure or nonsecure by blocks, using the block-based memory protection controller (MPCBB).

The granularity of SRAM secure block based is a page of 512 bytes.

3.6.2 SRAMs privilege protection

The SRAM1 and SRAM2 can be programmed as privileged or unprivileged by blocks, using the MPCBB. The granularity of SRAM block-based privilege is a page of 512 bytes.

3.7 TrustZone security architecture

The security architecture is based on Arm TrustZone with the Armv8-M main extension.

The TZEN option bit in the FLASH_OPTR register activates the TrustZone security.

When TrustZone is enabled, the SAU (security attribution unit) and IDAU (implementation defined attribution unit) define the access permissions based on secure and nonsecure state.

- SAU: up to eight SAU configurable regions are available for security attribution.
- IDAU: provides a first memory partition as nonsecure or nonsecure callable attributes. It is then combined with the results from the SAU security attribution and the higher security state is selected.

Based on IDAU security attribution, the flash memory, system SRAM and peripheral memory space is aliased twice for secure and nonsecure states.

Table 5 shows an example of typical SAU regions configuration based on IDAU regions.

Table 5. Example of memory map security attribution versus SAU configuration regions

<table>
<tr><th>Region description</th><th>Address range</th><th>IDAU security attribution</th><th>SAU security attribution typical configuration</th><th>Final security attribution</th></tr>
<tr><td>ICACHE Re-mappable (Reserved)</td><td>0x0000 0000
0x07FF FFFF</td><td>Nonsecure</td><td colspan="2">Secure or nonsecure or nonsecure callable</td></tr>
<tr><td rowspan="2">Code
flash memory and SRAM</td><td>0x0800 0000
0x0BFF FFFF</td><td colspan="3">Nonsecure</td></tr>
<tr><td>0x0C00 0000
0x0FFF FFFF</td><td>Nonsecure callable</td><td colspan="2">Secure or NSC</td></tr>
</table>

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Table 5. Example of memory map security attribution versus SAU configuration regions (contin-

Region description	Address range	IDAU security attribution	SAU security attribution typical configuration	Final security attribution
ICACHE Re-mappable (Reserved)	0x1000 0000 0x17FF FFFF	Nonsecure	Nonsecure	
	0x1800 0000 0x1FFF FFFF			
SRAM	0x2000 0000 0x2FFF FFFF	Nonsecure		
	0x3000_0000 0x3FFF FFFF	Nonsecure callable	Secure or nonsecure callable	
Peripherals	0x4000 0000 0x4FFF FFFF	Nonsecure		
	0x5000 0000 0x5FFF FFFF	Nonsecure callable	Secure or nonsecure callable	
Reserved	0x6000 0000 0xDFFF FFFF	Nonsecure	Secure or nonsecure or nonsecure callable	

3.7.1 TrustZone peripheral classification

When the TrustZone security is active, a peripheral can be either securable or TrustZone-aware type as follows:

- Securable: peripheral protected by an AHB/APB firewall gate that is controlled from TZSC to define security properties
- TrustZone-aware: peripheral connected directly to AHB or APB bus and implementing a specific TrustZone behavior such as a subset of registers being secure

3.7.2 Default TrustZone security state

The default system security state is detailed below:

- CPU: Cortex-M33 is in secure state after reset. The boot address must be in secure area.
- Memory map: SAU is fully secure after reset, hence all memory map is fully secure. Up to eight SAU configurable regions are available for security attribution.
- Flash memory:
  - Flash memory security area is defined by watermark user options.
  - Flash memory block based area is nonsecure after reset.
- SRAMs:
  - All are secure after reset, MPCBB is secure.
- Peripherals:
  - Securable peripherals are nonsecure after reset.
  - TrustZone-aware peripherals are nonsecure after reset.
- All GPIOs are secure after reset.

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- Interrupts:
  - NVIC: All interrupts are secure after reset. NVIC is banked for secure and nonsecure state.
  - TZIC: All illegal access interrupts are disabled after reset.

3.8 Boot modes

At startup, a BOOT0 pin, nBOOT0 and NSBOOTADDx[24:0] (x = 0, 1), and SECBOOTADD0[24:0] option bytes are used to select the boot memory address that includes:

- Boot from any address in user flash memory
- Boot from system memory bootloader
- Boot from any address in embedded SRAM
- Boot from RSS (root security services)

The BOOT0 value comes from the PH3-BOOT0 pin or from an option bit, depending upon the value of a user option bit to free the GPIO pad if needed.

The bootloader is located in the system memory, programmed by ST during production. It is used to program the flash memory by using USART, I^2C, SPI or USB OTG in device mode.

The bootloader is available on all devices. Refer to AN2606 *STM32 microcontroller system memory boot mode*, available on *www.st.com*, for more details.

The RSS are embedded in the flash memory area named secure information block, programmed during ST production. For example, the RSS enables the SFI (secure firmware installation), thanks to the RSSe (RSS extension firmware). This feature allows the customers to produce the confidentiality of the firmware to be provisioned into the STM32, when production is subcontracted to untrusted third party.

The RSS is available on all devices, after enabling the TrustZone through the TZEN option bit. Refer to AN4992 *STM32 MCUs secure firmware install (SFI) overview*, available on *www.st.com*, for more details.

Refer to *Table 6* and *Table 7*, respectively, for boot modes with TrustZone disabled and enabled.

Table 6. Boot modes when TrustZone is disabled (TZEN = 0)

nBOOT0 FLASH_ OPTR[27]	BOOT0 pin PH3	nSWBOOT0 FLASH_ OPTR[26]	Boot address option-bytes selection	Boot area	ST programmed default value
-	0	1	NSBOOTADD0[24:0]	Boot address defined by user option bytes NSBOOTADD0[24:0]	Flash memory: 0x08000 000
-	1	1	NSBOOTADD1[24:0]	Boot address defined by user option bytes NSBOOTADD1[24:0]	System bootloader: 0x0BF9 0000

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Table 6. Boot modes when TrustZone is disabled (TZEN = 0) (continued)

nBOOT0 FLASH_ OPTR[27]	BOOT0 pin PH3	nSWBOOT0 FLASH_ OPTR[26]	Boot address option-bytes selection	Boot area	ST programmed default value
1	-	0	NSBOOTADD0[24:0]	Boot address defined by user option bytes NSBOOTADD0[24:0]	Flash memory: 0x0800 0000
0	-	0	NSBOOTADD1[24:0]	Boot address defined by user option bytes NSBOOTADD1[24:0]	System bootloader: 0x0BF9 0000

Table 7. Boot modes when TrustZone is enabled (TZEN = 1)

BOOT_LOCK	nBOOT0 FLASH_ OPTR[27]	BOOT0 pin PH3	nSWBOOT0 FLASH_ OPTR[26]	RSS command	Boot address option bytes selection	Boot area	ST programmed default value
0	-	0	1	0	SECBOOT-ADD0[24:0]	Secure boot address defined by user option bytes SECBOOTADD0[24:0]	Flash memory: 0x0C00 0000
	-	1	1	0	N/A	RSS	RSS: 0x0FF8 0000
	1	-	0	0	SECBOOT-ADD0[24:0]	Secure boot address defined by user option bytes SECBOOTADD0[24:0]	Flash memory: 0x0C00 0000
	0	-	0	0	N/A	RSS	RSS: 0x0FF8 0000
	-	-	-	≠0	N/A	RSS	RSS: 0x0FF8 0000
1	-	-	-	-	SECBOOT-ADD0[24:0]	Secure boot address defined by user option bytes SECBOOTADD0[24:0]	Flash memory: 0x0C00 0000

When TrustZone is enabled by setting the TZEN option bit, the boot space must be in the secure area. The SECBOOTADD0[24:0] option bytes are used to select the boot secure memory address.

A unique boot entry option can be selected by setting the BOOT_LOCK option bit, allowing to boot always at the address selected by SECBOOTADD0[24:0] option bytes. All other boot options are ignored.

The boot address option bytes allow to program any boot memory address, but the allowed address space depends on the flash memory RDP level. If the programmed boot memory address is out of the allowed memory mapped area when RDP level is 0.5 or higher, the default boot address is forced either in secure or nonsecure flash memory, depending on TrustZone security option, as detailed in *Table 8*.

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Table 8. Boot space versus RDP protection

RDP	TZEN = 1	TZEN = 0
0	Any boot address	Any boot address
0.5	Boot address only in RSS or secure flash memory: 0x0C00 0000 - 0x0C1F FFFF. Otherwise, forced boot address is 0x0FF8 0000	N/A
1		Any boot address
2		Boot address only in flash memory: 0x0800 0000 - 0x081F FFFF. Otherwise, forced boot address is: 0x0800 0000

3.9 Global TrustZone controller (GTZC)

GTZC is used to configure TrustZone and privileged attributes within the full system.

The GTZC includes different sub-blocks:

- **TZSC**: TrustZone security controller

  Defines the secure/privilege state of slave/master peripherals. The TZSC block informs some peripherals (such as RCC or GPIO) about the secure status of each securable peripheral.
- **TZIC**: TrustZone illegal access controller

  Gathers all security illegal access events in the system and generates a secure interrupt towards NVIC.
- **MPCBB**: block-based memory protection controller

  Controls secure states of all memory blocks (512-byte pages) of the associated SRAM. This peripheral configures the internal RAM in a TrustZone system product having segmented SRAM with programmable-security and privileged attributes.

The GTZC main features are:

- Independent 32-bit AHB interfaces for TZSC, TZIC and MPCBB
- Secure and nonsecure access supported for privileged/unprivileged part of TZSC
- Set of registers to define product security settings:
  - Secure/privilege access mode for securable peripherals
  - Secure/privilege access mode for securable memories
  - Illegal access interrupt notification

3.10 2.4 GHz RADIO

The 2.4 GHz RADIO is ultra-low-power, operating in the 2.4 GHz ISM band. It provides Bluetooth LE 1 Mbps coded, 1 Mbps, and 2 Mbps noncoded GFSK, and IEEE802.15.4 chip rate 2 Mchip/s, spreading mode DSSS, data rate 125 kbps and 250 kbps, O-QPSK-C modulation. It is compliant with the Bluetooth 5.4, Matter, Thread, and Zigbee specifications, and with radio regulations including ETSI EN 300 328, EN 300 440, EN 301 489-17, ARIB STD-T66, FCC CFR47 part 15 section 15.205, 15.209, 15.247 and 15.249, IC RSS-139 and RSS-210.

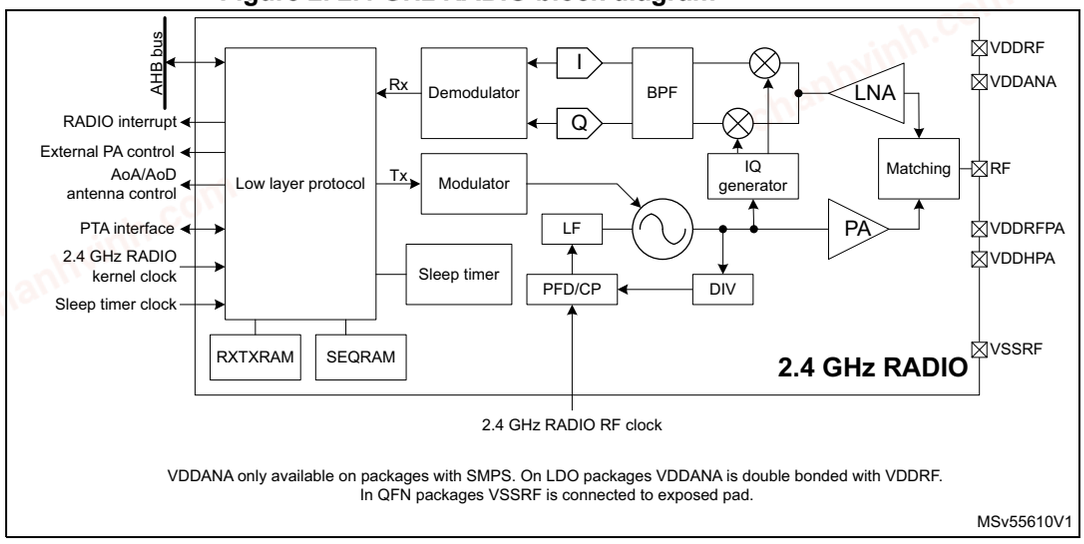
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The 2.4 GHz RADIO supports the following features:

- Radio protocol:
  - Bluetooth Low Energy
  - IEEE802.15.4
  - Proprietary protocols
  - Concurrent mode
- Bluetooth LE
  - Data rate 1 Mpbs, 2 Mbps, 500 kbps, and 125 kbps.
  - Device privacy and network privacy modes
  - Anonymous device address types
  - Advertising extension PDUs
  - Advertising channel index
  - Periodic advertising synchronous transfer
  - High duty cycle, nonconnectable advertising
  - Channel selection algorithm #2
  - Angle of arrival (AoA), angle of departure (AoD)
  - Up to 20 connections in any role in addition to advertiser and scanner roles
  - Audio connected isochronous streams
  - Audio broadcast isochronous streams
- IEEE 802.15.4 features:
  - Beacon management
  - 16-bit short and 64-bit IEEE addressing modes
  - PAN formation along with association and disassociation
  - Full handshake protocol for transfer reliability, frame validation, and acknowledgment frame delivery
  - IEEE802.15.4 2020 MAC for nonbeaconed PANs
- Matter
- Thread
- Zigbee
- External PA support
- Packet traffic arbitration

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Figure 2. 2.4 GHz RADIO block diagram



3.11 PTA interface

The PTA interface enables packet traffic arbitration with other connectivity devices, as WiFi

PTA main features:

- based on IEEE802.15.2 standard
- supports both grant and deny signaling
- supports from 1- up to 4-wire protocols
- programmable transmit receive PTA_STATUS polarity
- programmable priority polarity
- programmable grant polarity
- programmable active polarity
- programmable PTA_ACTIVE timing
- programmable PTA_STATUS time multiplexed priority timing
- programmable transmit packet abort

3.12 Power supply management

The power controller (PWR) main features are:

- Power supplies and supply domains
  - Core domain (V_{CORE})
  - V_{DD} and backup domain
  - Analog domain (V_{DDA})
  - SMPS power stage (V_{DDSMPS}, available only on SMPS packages)
  - V_{DDUSB} domain USB OTG (available only on USB packages)
  - V_{DDRF} for 2.4 GHz RADIO
- System supply voltage regulation
  - SMPS step-down converter

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  - Voltage regulator (LDO)
- Power supply supervision
  - BOR monitor
  - PVD monitor
- Power management
  - Operating modes
  - Voltage scaling control
  - Low-power modes
- TrustZone security and privilege protection

3.12.1 Power supply schemes

The devices require a 1.71 to 3.6 V V_{DD} operating voltage supply. Several independent supplies can be provided for specific peripherals:

- V_{DD} = 1.71 to 3.6 V (functionality guaranteed down to V_{BORx} minimum value)
  External power supply for the I/Os, the internal regulator, the system analog such as reset, power management, and internal clocks, and the backup domain. It is provided externally through the VDD pins. VDDRF must be connected to the same supply used for VDD.
- V_{DDIO2} = 1.08 to 3.6 V
  External power supply for 14 I/Os (GPIOG[15:2]). The V_{DDIO2} voltage level is independent from the V_{DD} voltage and must be connected to VDD (preferably) or to VSS pin when these I/Os are not used.
- V_{DDA} = 1.58 (COMP) / 1.62 (ADC) to 3.6 V
  External analog power supply for ADC and comparators. The V_{DDA} voltage level is independent from the V_{DD} voltage and must be connected to VDD (preferably) or to VSS pin when these peripherals are not used.
- V_{REF+}
  Reference voltage for the ADC. It is also the output of the internal voltage reference buffer (VREFBUF) when enabled. The V_{REF+} can be connected to VSS pin when ADC and VREFBUF are not used. The VREF+ pin is not available on all packages, when not available, it is bonded to VDDA.
- V_{DDUSB} = 3.0 to 3.6 V
  External power supply for the USB OTG transceiver. It is provided externally through the VDDUSB pin. The V_{DDUSB} voltage level is independent from the V_{DD} voltage and must be connected to VDD (preferably) or to VSS pin when the USB OTG is not used.
- V_{DDSMPS} = 1.71 to 3.6 V
  External power supply for the SMPS step down converter. It is provided externally through VDDSMPS supply pin, and must be connected to the same supply as V_{DD}.
- V_{LXSMPS} is the switched SMPS step down converter output.
  The SMPS power supply pins are available only on a specific package with SMPS step-down converter option.
- V_{DDRF} = 1.71 to 3.6 V
  External power supply for the 2.4 GHz RADIO, it must be connected to the same supply used for VDD.
- V_{DDANA} = 0 to 3.6 V (must be ≥ 1.2 V for 2.4 GHz RADIO operation)

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An external power supply for the 2.4 GHz RADIO, can be connected to V_{DD11}. The V_{DDANA} supply must be equal or lower than V_{DDRF}.

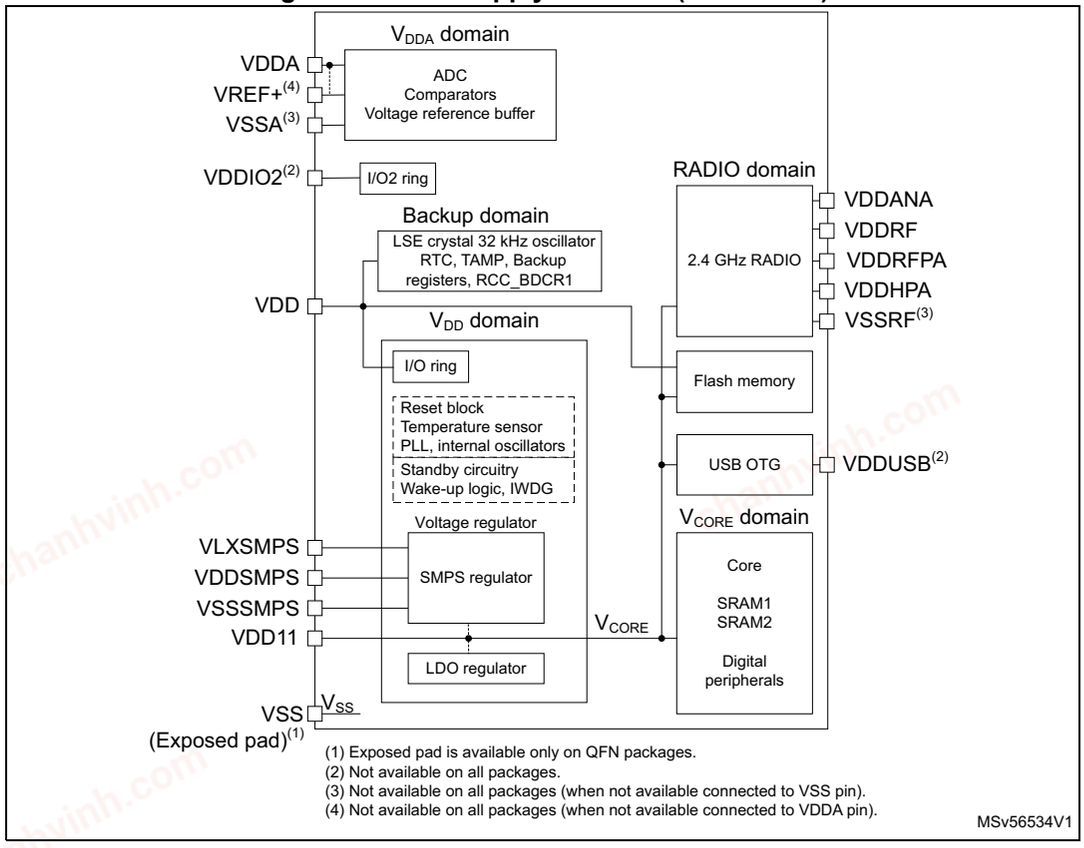
- V_{DDRFPA} = 0 to 3.6 V (must be ≥ 1.2 V for 2.4 GHz RADIO operation)
  An external power supply for the 2.4 GHz RADIO and power amplifier regulator, can be connected to V_{DD11}. The maximum reachable transmit output power is determined by V_{DDRFPA} supply level. The V_{DDRFPA} supply must be equal or lower than V_{DDRF}.

The devices embed two regulators: one LDO and one SMPS in parallel to provide the V_{CORE} supply for digital peripherals, SRAM1, SRAM2, 2.4 GHz RADIO and embedded flash memory. The LDO generates this voltage on VCAP pin connected to a 4.7 µF (typical) external capacitor. The SMPS generates this voltage on VDD11 pin, with a total a 4.7 µF (typical) external capacitor. The SMPS requires an external 2.2 µH (typical) coil.

Both regulators can provide two different voltages (voltage scaling), and can operate in Stop modes.

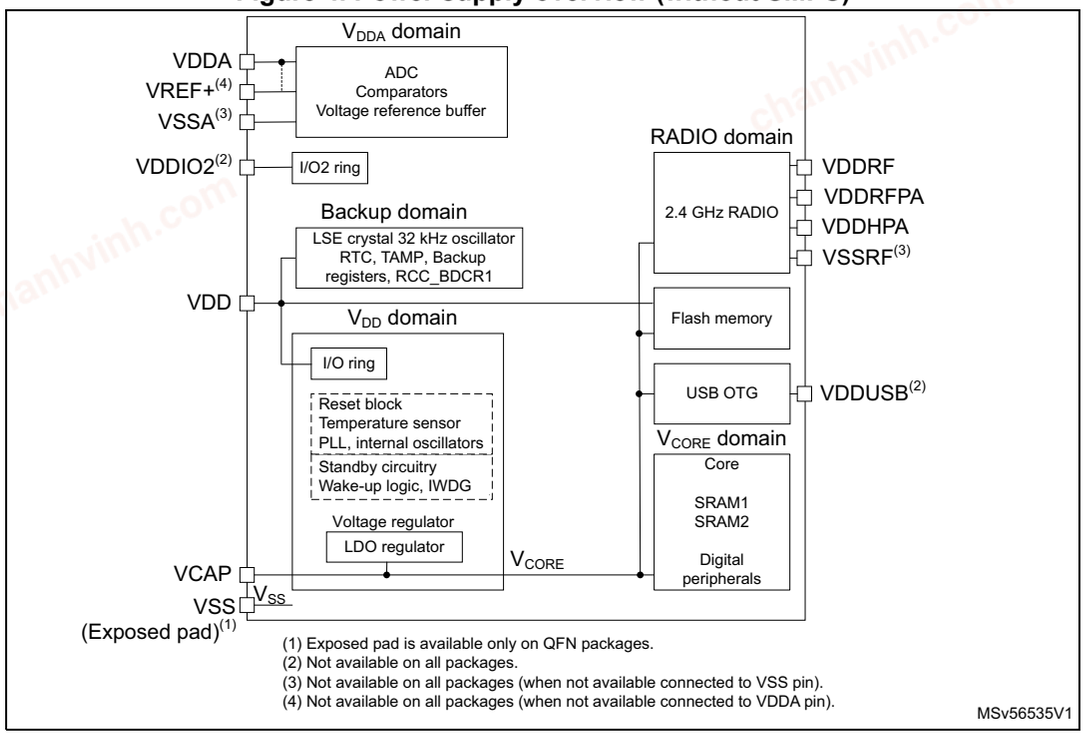
It is possible to switch from SMPS to LDO and from LDO to SMPS on-the-fly.

Figure 3. Power supply overview (with SMPS)



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Figure 4. Power supply overview (without SMPS)

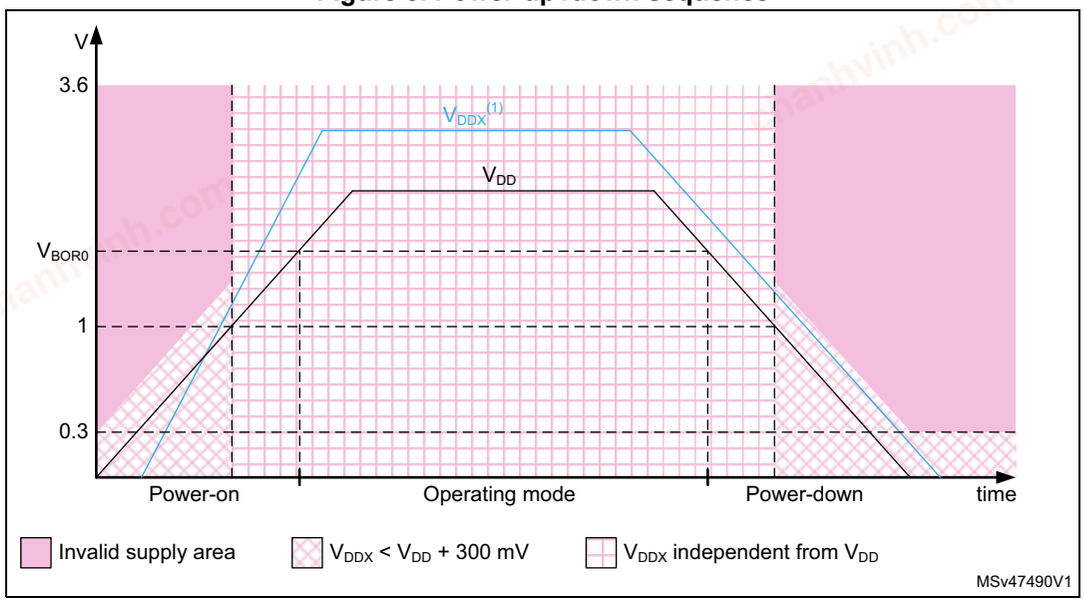


During power-up and power-down phases, the following power sequence requirements must be respected:

- When V_{DD} is below 1 V, other power supplies (namely V_{DDA}, V_{DDIO2}, V_{DDUSB}) must remain below V_{DD} + 300 mV.
- When V_{DD} is equal to or above 1 V, other power supplies are independent.
- During the power-down phase, V_{DD} can temporarily become lower than other supplies only if the energy provided to the MCU remains below 1 mJ. This allows external decoupling capacitors to be discharged with different time constants during the power-down transient phase.

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Figure 5. Power-up /down sequence



1. V_{DDX} refers to power supplies V_{DDA},V_{DDIO2}, and V_{DDUSB}.

3.12.2 Power supply supervisor

The devices have an integrated ultra-low-power BOR (brownout reset) active in all modes. The BOR ensures proper operation after power on and during power down. The devices remain in reset mode when the monitored supply voltage V_{DD} is below a specified threshold, without the need for an external reset circuit.

The lowest BOR level is 1.71 V at power on, and other higher thresholds can be selected through option bytes. The devices feature an embedded PVD (programmable voltage detector) that monitors the V_{DD} power supply and compares it to the V_{PVD} threshold.

An interrupt can be generated when V_{DD} drops below and/or rises above the V_{PVD} threshold. The interrupt service routine can then generate a warning message and/or put the MCU into a safe state. The PVD is enabled by software.

The devices support dynamic voltage scaling to optimize power consumption in Run mode. The voltage from the main regulator that supplies the logic (V_{CORE}) can be adjusted according to the system's maximum operating frequency.

The main regulator operates in the following ranges:

- Range 1 (V_{CORE} = 1.2 V) with CPU and peripherals running at up to 100 MHz
- Range 2 (V_{CORE} = 0.9 V) with CPU and peripherals running at up to 16 MHz

Low-power modes

The devices support different low-power modes to achieve the best compromise between low-power consumption, startup time, available peripherals, and available wake-up sources.

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Table 9. Operating modes overview

Mode	Regulator[1]	CPU	Flash memory	SRAM	Clocks	DMA and peripherals[2]	Wake-up source
Run	Range 1	Yes	ON[3]	ON	Any	All	N/A
	Range 2					All except USB OTG and 2.4 GHz RADIO	
Sleep	Range 1	No	ON	ON[4]	Any	All	Any interrupt or event
	Range 2					All except USB OTG and 2.4 GHz RADIO	
Stop 0	Range 1	No	OFF	ON[5]	LSE LSI[6]	BOR, PVD, RTC, TAMP, IWDG, SLEEP_TIMER, ADC4[7] (temperature sensor), COMPx (x = 1, 2), USARTx (x = 1..3)[8], LPUART1, SPIx (x = 1..3)[9], I2Cx (x = 1..4)[10], LPTIMx (x = 1, 2)[11], GPIO, GPDMA1[12], 2.4 GHz RADIO All other peripherals are frozen.	Reset pin, all I/Os, BOR, PVD, RTC, TAMP, IWDG, SLEEP_TIMER, ADC4 (temperature sensor), COMPx (x = 1, 2), USARTx (x = 1..3), LPUART1, SPIx (x = 1..3), I2Cx (x = 1..4), LPTIMx (x = 1, 2), GPDMA1, 2.4 GHz RADIO
	Range 2					All from Stop 0 Range 1 except USB OTG and 2.4 GHz RADIO	
Stop 1[13]	LPR	No	OFF	ON[5]	LSE LSI	BOR, PVD, RTC, TAMP, IWDG, SLEEP_TIMER, ADC4 (temperature sensor), COMPx (x = 1, 2), USARTx (x = 1..3), LPUART1, SPIx (x = 1..3), I2Cx (x = 1..4), LPTIMx (x = 1, 2), GPIO All other peripherals are frozen.	Reset pin, all I/Os, BOR, PVD, RTC, TAMP, IWDG, SLEEP_TIMER, ADC4 (temperature sensor), COMPx (x = 1, 2), USARTx (x = 1..3), LPUART1, SPIx (x = 1..3), I2Cx (x = 1..4), LPTIMx (x = 1, 2)

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Table 9. Operating modes overview (continued)

Mode	Regulator[1]	CPU	Flash memory	SRAM	Clocks	DMA and peripherals[2]	Wake-up source
Stop 2[14]	LPR	No	OFF	ON[5]	LSE LSI	BOR, PVD, RTC, TAMP, IWDG, SLEEP_TIMER, LPUART1, SPI3, I2C3, LPTIM1, GPIO All other peripherals are powered off.	Reset pin, all I/Os, BOR, PVD, RTC, TAMP, IWDG, SLEEP_TIMER, LPUART1, SPI3, I2C3, LPTIM1
Standby retention	LPR	Powered off	OFF	ON[5]	LSE LSI	BOR, RTC, TAMP, IWDG, SLEEP_TIMER All other peripherals are powered off. I/O configuration can be retained, floating, pull-up or pull-down.	Reset pin, WKUPx (x = 1...8), BOR, RTC, TAMP, IWDG, SLEEP_TIMER
Standby	OFF			Powered off		All from mode Standby retention, except SLEEP_TIMER	

1. LPR means that the main regulator is OFF and the low-power regulator is ON.
2. All peripherals can be active or clock gated to save power consumption.
3. The flash memory can be put in power-down and its clock can be gated off when executing from SRAM.
4. The SRAM1 and SRAM2 clocks can be gated on or off independently.
5. The SRAM can be individually powered off to save power consumption.
6. HSI16 can be temporary enabled upon peripheral request, for autonomous functions with DMA or wake-up from Stop event detections.
7. The ADC conversion is functional and autonomous with DMA in Stop 0 mode, and can generate a wake-up interrupt on conversion events.
8. UART and LPUART transmission and reception is functional and autonomous with DMA in Stop 0 mode, and can generate a wake-up interrupt on transfer events.
9. SPI transmission and reception is functional and autonomous with DMA in Stop 0 mode, and can generate a wake-up interrupt on transfer events.
10. I2C transmission and reception is functional and autonomous with DMA in Stop 0 mode, and can generate a wake-up interrupt on transfer events.
11. LPTIM is functional and autonomous with DMA in Stop 0 mode, and can generate a wake-up interrupt on all events.
12. GPDMA is functional and autonomous in Stop 0 mode, and can generate a wake-up interrupt on events.
13. Active peripherals ADC, COMP, USART, LPUART, SPI, I2C and LPTIM, can generate bus clock request and/or a wake-up interrupt on event.
14. Active peripherals LPUART1, SPI3, I2C3 and LPTIM1, can generate bus clock request and/or a wake-up interrupt on event.

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By default, the microcontroller is in Run mode after a system or a power on reset. It is up to the user to select one of the low-power modes described below:

- **Sleep** mode

  In Sleep mode, only the CPU is stopped. All peripherals continue to operate and can wake up the CPU when an interrupt or event occurs.

- **Stop 0 and Stop 1** modes

  Stop modes achieve the lowest power consumption while retaining the content of SRAM and registers. All clocks in the V_{CORE} domain are stopped, the PLL, the HSI16, and the HSE32 crystal oscillators are disabled. The LSE or LSI is still running.

  The RTC, TAMP, IWDG and SLEEP_TIMER can remain active.

  Some peripherals are autonomous and can operate in Stop modes by requesting their kernel clock and their bus clock when needed, to transfer data with DMA Stop 0 modes will be entered. Refer to *PWR background autonomous mode (BAM)* for more details. In Stop modes the bus clocks when requested use HSI16.

  Stop 0 offer the largest number of active peripherals, with or without DMA, and wake-up sources, a smaller wake-up time but a higher consumption than Stop 1.

  In Stop 0 mode, the main regulator remains ON, allowing a very fast wake-up time, but with higher power consumption.

  Stop 1 is the lowest power mode with full retention, but the functional peripherals and sources of wake-up are reduced.

  The BOR can be configured in ultra-low-power mode to further reduce consumption during Stop 1 mode.

  The system clock when exiting from Stop 0 or Stop 1 modes is HSI16.

- **Stop 2** mode

  Stop mode achieves the lowest power consumption while retaining the content of SRAM and some registers. All clocks in the V_{CORE} domain are stopped, the PLL, the HSI16, and the HSE32 crystal oscillators are disabled. The LSE or LSI is still running.

  The RTC, TAMP, IWDG and SLEEP_TIMER can remain active.

  A reduced set of peripherals are autonomous and can operate in Stop 2 mode by requesting their kernel clock and their bus clock when needed. Refer to *PWR background autonomous mode (BAM)* for more details.

  Stop 2 is the lowest power mode with partial retention, but the functional peripherals and sources of wake-up are reduced.

  The BOR can be configured in ultra-low-power mode to further reduce power consumption during Stop 2 mode.

  The system clock when exiting from Stop 2 modes is HSI16.

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- **Standby retention and Standby** modes

  The Standby mode is used to achieve the lowest power consumption. The internal regulator is switched off so that the V_{CORE} domain is powered off. The PLL, the HSI16 and the HSE32 crystal oscillators are also switched off. The LSE or LSI is still running.

  The RTC and IWDG can remain active.

  The BOR always remains active in Standby mode.

  The BOR can be configured in ultra-low-power mode to further reduce power consumption during Standby mode.

  The state of each I/O during Standby mode can be retained with internal pull-up, internal pull-down or floating.

  After entering Standby mode, SRAMs and register contents are lost except for registers in the Backup domain and Standby circuitry. Optionally, the full SRAM1 and/or SRAM2 can be retained in Standby mode, supplied by the low-power regulator (Standby with RAM retention mode). Also optionally the 2.4 GHz RADIO can be retained in Standby mode, supplied by the low-power regulator (Standby with 2.4 GHz RADIO retention mode).

  The device exits Standby modes when an external reset (NRST pin), an IWDG event or reset, WKUP pin event (configurable rising or falling edge), an RTC event occurs (alarm, periodic wake-up, timestamp), or a tamper detection. The tamper detection can be raised either due to external pins or due to an internal failure detection.

  When in Standby with 2.4 GHz RADIO retention mode also the SLEEP_TIMER can exit the device from Standby mode.

  The system clock after wake-up is HSI16.

PWR background autonomous mode (BAM)

The devices support BAM (background autonomous mode), that allows peripherals to be functional and autonomous in Stop mode (Stop 0, Stop 1 and Stop 2 modes), so without any software running.

In Stop 0 modes, the autonomous peripherals are the following: ADC4, LPTIMx (x = 1, 2), USARTx (x = 1..3), LPUART1, SPIx (x = 1..3), I2Cx (x = 1..4), 2.4 GHz RADIO and GPDMA1. In this mode the GPDMA1 can be used to transfer data or control peripherals and access SRAM1 and SRAM2. The ADC4 can also be used to measure temperature. The 2.4 GHz RADIO is only autonomous in Stop 0 range 1.

In Stop 1 mode, the autonomous peripherals are the following: ADC4, LPTIMx (x = 1, 2), USARTx (x = 1..3), LPUART1, SPIx (x = 1..3), I2Cx (x = 1..4). These peripherals can request a transition to Stop 0 mode allowing then data transfers with GPDMA1.

In Stop 2 mode, the autonomous peripherals are the following: LPTIM1, LPUART1, SPI3, I2C3. These peripherals can request a transition to Run mode allowing then data transfers.

Those peripherals support the features detailed below:

- Functionality in Stop mode thanks to its own independent clock (named kernel clock) request capability: the peripheral kernel clock is automatically switched on when requested by a peripheral, and automatically switched off when no peripheral requests it.
- DMA transfers supported in Stop 0 mode thanks to system clock request capability: the system clock (HSI16) automatically switched on when requested by a peripheral, and automatically switched off when no peripheral requests it. When the system clock is requested by an autonomous peripheral, Stop 0 mode is automatically entered and the

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system clock is woken up and distributed to all peripherals enabled in the RCC. This allows the DMA to access the enabled SRAM, and any enabled peripheral register (for instance GPIO registers). When no peripheral requests its bus clock Stop 1 mode is automatically re-entered when Stop 1 mode selected as low-power mode.

- Automatic start of the peripheral thanks to hardware synchronous or asynchronous triggers (such as I/Os edge detection and low-power timer event).
- Wake-up from Stop mode with peripheral interrupt.

The GPDMA is fully functional and the linked-list is updated in Stop 0 mode, allowing the different DMA transfers to be linked without any CPU wake-up. This can be used to chain different peripherals transfers, or to write peripherals registers in order to change their configuration while remaining in Stop 0 mode.

The DMA transfers from memory to memory can be started by hardware synchronous or asynchronous triggers, and the DMA transfers between peripherals and memories can also be gated by those triggers.

Here below some use-cases that can be done while remaining in Stop mode:

- A/D conversion triggered by a low-power timer (or any other trigger)
  - wake-up from Stop mode on analog watchdog if the A/D conversion result is out of programmed thresholds
  - wake-up from Stop mode on DMA buffer event
- I^2C slave reception or transmission, SPI reception, UART/LPUART reception
  - wake-up at the end of peripheral transfer or on DMA buffer event
- I^2C controller transfer, SPI transmission, UART/LPUART transmission, triggered by a low-power timer (or any other trigger):
  - example: sensor periodic read
  - wake-up at the end of peripheral transfer or on DMA buffer event
- Bridges between peripherals
  - example: ADC converted data transferred by communication peripherals
- Data transfer from/to GPIO to/from SRAM for:
  - controlling external components
  - implementing data transmission and reception protocols

Table 10. Functionalities depending on the working mode(1)

Peripheral	Run		Sleep		Stop 0			Stop 1		Stop 2		Standby retention		Standby	
	Range 1	Range 2	Range 1	Range 2	Range 1	Range 2	Wake-up capability	-	Wake-up capability	-	Wake-up capability	-	Wake-up capability	-	Wake-up capability
CPU	Y		R		R		-	R	-	R	-	-	-	-	-
Flash memory	O(2)		O(2)		R		-	R	-	R	-	R	-	R	-
Flash interface	O		R		R		-	R	-	R	-	-	-	-	-
SRAM1	O		O		O(3)		-	O(3)	-	O(3)	-	O(3)	-	-	-
SRAM2	O		O		O(3)		O(4)	O(3)		O(3)		O(3)	-	-	-

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Table 10. Functionalities depending on the working mode(1) (continued)

Peripheral	Run		Sleep		Stop 0			Stop 1		Stop 2		Standby retention		Standby	
	Range 1	Range 2	Range 1	Range 2	Range 1	Range 2	Wake-up capability	-	Wake-up capability	-	Wake-up capability	-	Wake-up capability	-	Wake-up capability
RAMCFG	O		R		R		-	R	-	R	-	-	-	-	-
Backup registers	O		O		O		-	R	-	R	-	R	-	R	-
PWR	O		O		R		-	R(5)	-	R(5)	-	-	-	-	-
RCC	O		O		R(6)		-	R(6)	-	R(6)	-	-	-	-	-
EXTI	O		R		R		-	R	-	R	-	-	-	-	-
SYSCFG	O		R		R		-	R	-	R	-	-	-	-	-
ICACHE	O		R		R		-	R	-	R	-	-	-	-	-
2.4 GHz RADIO	O	R	O	R	O	R	O	R	-	-	-	-	-	-	-
2.4 GHz RADIO SRAM	O	R	O	R	O	R	-	R	-	R	-	R	-	-	-
PTACONV	O		O		O	R	-	R	-	-(7)	-	-	-	-	-
SLEEP_TIMER	O		O		O		O	O	O	O	O	O	O	-	-
BOR	Y		Y		Y		Y	Y	Y	Y	Y	Y	Y	Y	Y
PVD	O		O		O		O	O	O	O	O	-	-	-	-
HSI16	O		O		O(8)		-	O(8)	-	O(8)	-	-	-	-	-
HSE32	O		O		O(9)	-	-	-	-	-	-	-	-	-	-
LSI	O		O		O		-	O	-	O	-	O	-	O	-
LSE	O		O		O		-	O	-	O	-	O	-	O	-
HSECSS	O		O		O	-	O	-	-	-	-	-	-	-	-
LSECSS	O		O		O		O	O	O	O	O	O	O	O	O
IWDG	O		O		O		O	O	O	O	O	O	O	O	O
RTC	O		O		O		O	O	O	O	O	O	O	O	O
TAMP tamper pins	Up to 6		Up to 6		Up to 6		O	Up to 6	O	Up to 6	O	Up to 6	O	Up to 6	O
GPIO pins	O		O		O		O	O	O	O	O	O/R (10)	O (11)	O/R (10)	O(11)
USARTx (x = 1..3)	O		O		O		O(12)	O	O(12)	-	-	-	-	-	-
LPUART1	O		O		O		O(12)	O	O(12)	O	O(12)	-	-	-	-
I2Cx (x = 1, 2, 4)	O		O		O		O(13)	O	O(13)	-	-	-	-	-	-
I2C3	O		O		O		O(13)	O	O(13)	O	O(13)	-	-	-	-
SPIx (x = 1, 2)	O		O		O		O(14)	O	O(14)	-	-	-	-	-	-

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Table 10. Functionalities depending on the working mode(1) (continued)

Peripheral	Run		Sleep		Stop 0			Stop 1		Stop 2		Standby retention		Standby	
	Range 1	Range 2	Range 1	Range 2	Range 1	Range 2	Wake-up capability	-	Wake-up capability	-	Wake-up capability	-	Wake-up capability	-	Wake-up capability
SPI3	O		O		O		O(14)	O	O(14)	O	O(14)	-	-	-	-
ADC4	O		O		O		O(15)	O	O(15)	-	-	-	-	-	-
COMPx (x = 1, 2)	O		O		O		O	O	O	-	-	-	-	-	-
LPTIM1	O		O		O		O(16)	O	O(16)	O	O(16)	-	-	-	-
LPTIM2	O		O		O		O(16)	O	O(16)	-	-	-	-	-	-
GPDMA1	O		O		O		O(17)	R	-	-	-	-	-	-	-
USB OTG	O	-	O	-	R	-	O	-	-	-	-	-	-	-	-
TIMx (x = 1, 2, 3, 4, 16, 17)	O		O		R		-	R	-	-	-	-	-	-	-
SAI1	O		O		R		-	R	-	-	-	-	-	-	-
TSC	O		O		R		-	R	-	-	-	-	-	-	-
RNG	O		O		R		-	R	-	-	-	-	-	-	-
AES and SAES	O		O		R		-	R	-	-	-	-	-	-	-
PKA	O		O		R		-	R	-	-	-	-	-	-	-
HASH	O		O		R		-	R	-	-	-	-	-	-	-
CRC	O		O		R		-	R	-	-	-	-	-	-	-
HSEM	O		R		R		-	R	-	-	-	-	-	-	-
GTZC_TZSC	O		R		R		-	R	-	R	-	-	-	-	-
GTZC_TZIC	O		R		R		-	R	-	R	-	-	-	-	-
GTZC_MPCBB1	O		R		R		-	R	-	R	-	-	-	-	-
GTZC_MPCBB2	O		R		R		-	R	-	R	-	-	-	-	-
GTZC_MPCBB6	O		R		R		-	R	-	R	-	-	-	-	-
WWDG	O		O		R		-	R	-	R	-	-	-	-	-
SysTick timer	O		O		R		-	R	-	R	-	-	-	-	-
DBGMCU	O		O		O(18)		-	O (18)	-	O (18)	-	O (19)	-	O (19)	-

1. Legend: Y = yes (enabled). O = optional (disabled by default, can be enabled by software).R = retained, - = not available.
   Gray cells highlight the wake-up capability in each mode.
2. The flash memory can be configured in power-down mode. By default, it is not in power-down mode.
3. The SRAMs can be powered on or off independently.
4. Parity error interrupt or NMI wake-up from Stop mode.
5. PWR voltage scaling is reset to range 2.
6. RCC sysclk source is reset to HSI16.

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7. PTACONV interface signal levels can be retained on GPIOs.
8. Some peripherals with autonomous mode and wake-up from Stop capability can request HSI16 to be enabled. In this case, the oscillator is woken up by the peripheral, and is automatically put off when no peripheral needs it.
9. The 2.4 GHz RADIO peripheral in autonomous mode request HSE32 to be enabled. In this case, the oscillator is kept active by the peripheral, and is automatically put off when it no longer needs it.
10. I/O levels can be retained with pull-up, pull-down, or floating.
11. There are 16 wake-up pins available.
12. UART and LPUART reception and transmission are functional and autonomous in Stop mode in asynchronous and in SPI master modes, and generate a wake-up interrupt on transfer events.
13. I2C reception and transmission is functional and autonomous in Stop mode and generates a wake-up interrupt on transfer events.
14. SPI reception and transmission is functional and autonomous in Stop mode and generates a wake-up interrupt on transfer events.
15. A/D conversion is functional and autonomous in Stop mode, and generates a wake-up interrupt on conversion events.
16. LPTIM is functional and autonomous in Stop mode, and generates a wake-up interrupt on events.
17. GPDMA transfers are functional and autonomous in Stop 0 mode, and generates a wake-up interrupt on transfer events.
18. DBGMCU remains accessible trough AP0.
19. DBGMCU remains accessible through AP0 when CDBGPWRUPREQ is set.

3.12.3 Reset mode

To improve the consumption under reset, the I/Os state under and after reset is “analog state” (the I/O Schmitt trigger is disabled). In addition, the internal reset pull-up is deactivated when the reset source is internal.

3.12.4 PWR TrustZone security

When TrustZone security is activated by the TZEN option bit, the PWR is switched in TrustZone security mode.

The PWR TrustZone security secures the following configuration:

- Low-power mode
- WKUP (wake-up) pins
- Voltage detection
- Backup domain control

Some of the PWR configuration bits security is defined by the security of other peripherals:

- The VOS (voltage scaling) configuration is secure when the system clock selection is secure in RCC.
- The I/O Standby mode retention configuration is secure when the corresponding GPIO is secure.

3.13 Reset and clock controller (RCC)

The RCC (reset and clock controller) manages device and peripheral reset and distributes the clocks coming from the different oscillators to the core and to the peripherals. It also manages the clock gating for low-power modes and ensures the clock robustness. It features:

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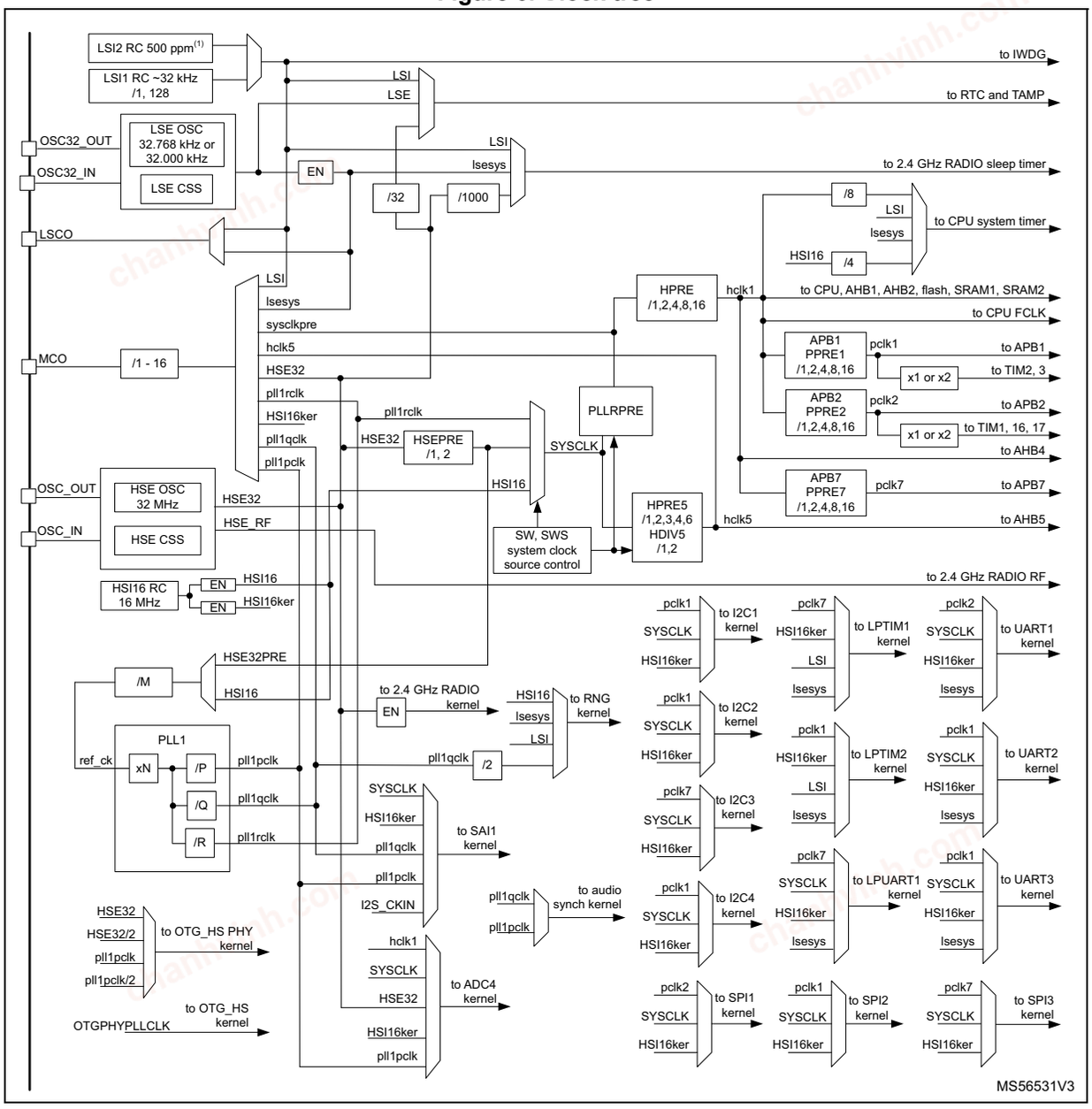
- Device reset source monitoring.
- Individual peripheral reset control.
- Clock prescaler: to get the best trade-off between speed and current consumption, the clock frequency to the CPU and peripherals can be adjusted by a programmable prescaler.
- Clock selection system: clock sources can be changed safely on-the-fly in Run mode through a configuration register.
- Clock management: in order to reduce the power consumption, the clock controller can stop the clock to the core, individual peripherals or memory.
- System clock source: different clock sources can be used to drive the system clock SYSCLK:
  - HSE32 (32 MHz high-speed external crystal oscillator), trimmable by software. The HSE32 can also be used with an external clock.
  - HSI16 (16 MHz high-speed internal RC oscillator), trimmable by software.
  - System PLL, can be fed by HSE32 or HSI16 with a maximum output frequency at 100 MHz.
- Auxiliary clock source: two ultra-low-power clock sources that can be used to drive e.g. the real-time clock:
  - LSE (32.000 kHz or 32.768 kHz low-speed external crystal oscillator), supporting programmable drive capability modes. The LSE can also be configured in bypass mode for an external clock.
  - LSI (~32 kHz low-speed internal RC oscillators), also used to drive the independent watchdog.
    The LSI1 clock absolute accuracy is ±5%, it can be divided by 128 to output a 250 Hz source clock.
    The LSI2 clock has a high stability, ±500 ppm. It can be used to drive the 2.4 GHz RADIO sleep timer.
- Peripheral clock sources: several peripherals have their own independent kernel clock whatever the system clock. The PLL has three independent outputs allowing the highest flexibility and can generate clocks for the ADC, SAI, USB OTG and the RNG.
- Startup clock: after reset, the microcontroller restarts by default with the HSI16. The prescaler ratio and clock source can be changed by the application program as soon as the code execution starts.
- CSS (Clock security systems): these features can be enabled by software.
  - If a HSE32 clock failure occurs, the system clock automatically switches to HSI16 and a software interrupt is generated if enabled.
  - LSE failure can also be detected and generates an interrupt, in this case the clock switches to LSI.
- Clock-out capability:
  - MCO (microcontroller clock output): outputs one of the internal clocks for external use by the application. (only available in Run, Sleep and Stop mode)
  - LSCO (low-speed clock output): outputs LSI or LSE in all operating modes.

Several prescalers allow AHB and APB frequencies configuration. The maximum frequency of the AHB and the APB clock domains is 100 MHz, except for AHB5 domain, which is limited to maximum 32 MHz.

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Figure 6. Clock tree



3.13.1 RCC TrustZone security

When the TrustZone security is activated by the TZEN option bit, the RCC is switched in TrustZone security mode.

The RCC TrustZone security secures some RCC system configuration and peripheral configuration from being read or modified by nonsecure accesses: when a peripheral is secure, the related peripheral clock, reset, clock source selection and clock enable during low-power modes control bits are secure.

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A peripheral is in secure state:

- For securable peripherals, when the corresponding SEC security bit is set in the TZSC (TrustZone security controller).
- For TrustZone-aware peripherals, when a security feature of the peripheral is enabled through dedicated peripheral bits.

3.14 General-purpose input/output (GPIO)

Each of the GPIO pins can be configured by software as output (push-pull or open-drain), as input (with or without pull-up or pull-down) or as peripheral alternate function. Most of the GPIO pins are shared with digital or analog alternate functions.

After reset, all GPIOs are in analog mode to reduce power consumption.

The I/Os alternate function configuration can be locked, if needed, following a specific sequence, to avoid spurious writing to the I/Os registers.

The GPIO allows dynamic I/O control in Stop 0 mode thanks to GPDMA1. All I/Os can be configured and controlled as input or output (open-drain or push-pull depending on GPIO configuration).

When enabled in the PWR, latest I/Os output level can be retained by pulling the I/Os high or low before entering Standby mode. I/O levels are retained after exit from Standby mode, until they are reconfigured by software.

3.14.1 GPIO TrustZone security

Each I/O pin of GPIO port can be individually configured as secure. When the selected I/O pin is configured as secure, its corresponding configuration bits for alternate function, mode selection, I/O data are secure against a nonsecure access. The associated registers bit access is restricted to a secure software only. After reset, all GPIO ports are secure.

3.15 System configuration controller (SYSCFG)

The main purpose of the SYSCFG (system configuration controller) are the following:

- Managing robustness features
- Configuring FPU interrupts
- Enabling/disabling the I^2C fast-mode plus (FMP) high-drive mode of some I/Os and booster for I/Os analog switches
- Managing the I/O compensation
- Provides memory erase status
- Communication channel with the RSS

3.15.1 SYSCFG TrustZone security

When TrustZone security is activated by the TZEN option bit, the SYSCFG is switched in TrustZone security mode.

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The SYSCFG TrustZone security secures the following configuration:

- FPU interrupt configuration
- Robustness features
- I/O compensation and memory erase status

Some of the SYSCFG configuration bits security is defined by the security of other peripherals:

- The FMP high-drive mode of some I/Os configuration is secure when the corresponding GPIO is secure.
- The booster for I/Os analog switches configuration is secure when the ADC4 is secure.

3.16 Peripheral interconnect matrix

Several peripherals have direct connections between them, enabling autonomous communication between them, and saving CPU resources (and power consumption). In addition, these hardware connections allow fast and predictable latency.

Depending on the peripherals, these interconnections can operate in Run, Sleep and Stop modes.

3.17 General purpose direct memory access controller (GPDMA)

The general purpose direct memory access (GPDMA) controller is a bus master and system peripheral.

The GPDMA is used to perform programmable data transfers between memory-mapped peripherals and/or memories via linked-lists, upon the control of an off-loaded CPU.

The GPDMA main features are:

- Dual bidirectional AHB master
- Memory-mapped data transfers from a source to a destination:
  - Peripheral-to-memory
  - Memory-to-peripheral
  - Memory-to-memory
  - Peripheral-to-peripheral
- Autonomous data transfers during Run, Sleep and Stop 0 modes
- Transfers arbitration based on a four-grade programmed priority at a channel level:
  - One high-priority traffic class, for time-sensitive channels (queue 3)
  - Three low-priority traffic classes, with a weighted round-robin allocation for nontime-sensitive channels (queues 0, 1, 2)
- Per channel event generation, on any of the following events: transfer complete or half transfer complete or data transfer error or user setting error, and/or update linked-list item error or completed suspension
- Per channel interrupt generation, with separately programmed interrupt enable per event
- Eight concurrent DMA channels:
  - Per channel FIFO for queuing source and destination transfers

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  - Intra-channel DMA transfers chaining via programmable linked-list into memory, supporting two execution modes: run-to-completion and link step mode
  - Intra-channel and inter-channel DMA transfers chaining via programmable DMA input triggers connection to DMA task completion events
- Per linked-list item within a channel:
  - Separately programmed source and destination transfers
  - Programmable data handling between source and destination: byte-based reordering, packing or unpacking, padding or truncation, sign extension and left/right realignment
  - Programmable number of data bytes to be transferred from the source, defining the block level
  - Linear source and destination addressing: either fixed or contiguously incremented addressing, programmed at a block level, between successive single transfers
  - Programmable DMA request and trigger selection
  - Programmable DMA half-transfer and transfer complete events generation
  - Pointer to the next linked-list item and its data structure in memory, with automatic update of the DMA linked-list control registers
- Debug:
  - Channel suspend and resume support
  - Channel status reporting including FIFO level and event flags
- TrustZone support:
  - Support for secure and nonsecure DMA transfers, independently at a first channel level, and independently at a source/destination and link sub-levels
  - Secure and nonsecure interrupts reporting, resulting from any of the respectively secure and nonsecure channels
  - TrustZone-aware AHB slave port, protecting any DMA secure resource (register, register field) from a nonsecure access
- Privileged/unprivileged support:
  - Support for privileged and unprivileged DMA transfers, independently at a channel level
  - Privileged-aware AHB slave port.

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Table 11. GPDMA1 channels implementation and usage

Channel x	Hardware parameters		Features
	dma_fifo_size[x]	dma_addressing[x]	
x = 0 to 5	2	0	Channel x is implemented with: – a FIFO of 8 bytes, 2 words – fixed/contiguously incremented addressing These channels may be also used for GPDMA transfers, between an APB or AHB peripheral and SRAM.
x = 6 to 7	4	0	Channel x is implemented with: – a FIFO of 32 bytes, 8 words – fixed/contiguously incremented addressing These channels may be also used for GPDMA transfers, between a demanding AHB or APB peripheral and SRAM.

Table 12. GPDMA1 autonomous mode and wake-up in low-power modes

Feature	Low-power modes
Autonomous mode and wake-up	Sleep, Stop 0 modes

3.18 Interrupts and events

3.18.1 Nested vectored interrupt controller (NVIC)

The devices embed a nested vectored interrupt controller (NVIC) that is able to manage 16 priority levels and to handle up to 70 maskable interrupt vectors plus the 16 interrupt vectors of the Cortex-M33.

The NVIC benefits are the following:

- closely coupled NVIC giving low-latency interrupt processing
- interrupt entry vector table address passed directly to the core
- early processing of interrupts
- processing of late arriving higher priority interrupts
- support for tail chaining
- processor state automatically saved
- interrupt entry restored on interrupt exit with no instruction overhead
- TrustZone support: NVIC registers banked across secure and nonsecure states

The NVIC hardware block provides flexible interrupt management features with minimal interrupt latency.

3.18.2 Extended interrupt/event controller (EXTI)

The extended interrupts and event controller (EXTI) manages the individual CPU and system wake-up through configurable event inputs. It provides wake-up requests to the

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power control, and generates an interrupt request to the CPU NVIC and events to the CPU event input.

The EXTI wake-up requests allow the system to be woken up from Stop modes.

The interrupt request and event request generation can also be used in Run and Sleep modes. The EXTI also includes the peripheral interconnect EXTI multiplexer I/O port selection.

The EXTI main features are the following:

- All event inputs allowed to wake up the system
- Configurable events (signals from I/Os or peripherals able to generate a pulse)
  - Selectable active trigger edge
  - Interrupt pending status register bit independent for the rising and falling edge
  - Individual interrupt and event generation mask, used for conditioning the CPU wake-up, interrupt and event generation
  - Software trigger possibility
- TrustZone secure events
  - The access to control and configuration bits of secure input events can be made secure
- EXTI I/O port selection for peripheral interconnect use.

3.19 Cyclic redundancy check calculation unit (CRC)

The CRC is used to get a CRC code using a configurable generator with polynomial value and size.

Among other applications, the CRC-based techniques are used to verify data transmission or storage integrity. In the scope of the EN/IEC 60335-1 standard, they offer a mean to verify the flash memory integrity.

The CRC calculation unit helps to compute a signature of the software during runtime, that can be ulteriorly compared with a reference signature generated at link-time and that can be stored at a given memory location.

3.20 Analog-to-digital converter (ADC4)

The devices embed one 12-bit successive approximation analog-to-digital converter.

Table 13. ADC features

ADC modes/features(1)	ADC4
Resolution	12 bits
Maximum sampling speed for 12-bit resolution	2.5 Msps
Hardware offset calibration	X
Hardware linearity calibration	-
Single-ended inputs	X
Differential inputs	-

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Table 13. ADC features (continued)

ADC modes/features[1]	ADC4
Injected channel conversion	-
Oversampling	Up to x256
Data register	16 bits
DMA support	X
Autonomous mode	X
Offset compensation	-
Gain compensation	-
Number of analog watchdogs	3
Wake-up from Stop mode	X

1. X = supported.

ADC4 has up to 19 multiplexed channels, allowing it to measure signals from up to 10 external and 3 internal sources (the other channels are reserved). The conversion of the various channels can be performed in Single, Continuous, Scan or Discontinuous mode. The result of is stored in a left-aligned or right-aligned 16-bit data register.

The analog watchdog feature allows the application to detect if the input voltage goes outside the user-defined higher or lower thresholds.

An efficient low-power mode is implemented to allow very low consumption at low frequency. The ADC4 is autonomous in low-power modes down to Stop modes.

A built-in hardware oversampler allows analog performances to be improved while off-loading the related computational burden from the CPU.

The ADC4 main features are:

- High performance
  - 12-, 10-, 8- or 6-bit configurable resolution
  - ADC conversion time: 0.4 µs for 12-bit resolution (2.5 MHz), faster conversion times obtained by lowering resolution
  - Self-calibration
  - Programmable sampling time
  - Data alignment with built-in data coherency
  - DMA support
- Low-power
  - PCLK frequency reduced for low-power operation while still keeping optimum ADC performance
  - Wait mode: ADC overrun prevented in applications with low frequency PCLK
  - Auto-off mode: ADC automatically powered off except during the active conversion phase, dramatically reducing the ADC power consumption
  - Autonomous mode: in low-power modes (down to Stop 1), the ADC4 automatically switches on when a trigger occurs to start conversion, and it automatically switches off after conversion. Data are transfered to SRAM with DMA.
  - ADC4 interrupts wake up the device down to Stop 1 mode.

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- Analog input channels
  - Up to 10 external analog inputs
  - One channel for the internal temperature sensor (V_{SENSE})
  - One channel for the internal reference voltage (V_{REFINT})
  - One channel for the internal digital core voltage (V_{CORE})
- Start-of-conversion can be initiated:
  - By software
  - By hardware triggers with configurable polarity (timer events or GPIO input events)
- Conversion modes
  - Conversion of a single channel or scan of a sequence of channels
  - Selected inputs converted once per trigger in Single mode
  - Selected inputs converted continuously in Continuous mode
  - Discontinuous mode
- Interrupt generation at the end of sampling, end of conversion, end of sequence conversion, and in case of analog watchdog or overrun events, with wake-up from Stop capability
- Three analog watchdogs
- ADC supply requirements: 1.62 to 3.6 V
- ADC input range: $V_{SSA} < V_{IN} < V_{DDA}$

Note: The ADC4 analog block clock frequency after the ADC4 prescaler must be between 140 kHz and 55 MHz.

Note: V_{SSA} is connected to package pin VSS.

3.20.1 Temperature sensor (V_{SENSE})

The temperature sensor generates a voltage V_{SENSE} that varies linearly with temperature. The temperature sensor is internally connected to ADC4 input channel that is used to convert the sensor output voltage into a digital value.

The sensor provides good linearity but it must be calibrated to obtain a good accuracy of the temperature measurement. As the offset of the temperature sensor varies from chip to chip due to process variation, the uncalibrated internal temperature sensor is suitable for applications that detect temperature changes only.

To improve the accuracy of the temperature sensor measurement, each device is individually factory-calibrated by ST. The temperature sensor factory calibration data are stored by STMicroelectronics in the system memory area, accessible in read-only mode.

Table 14. Temperature sensor calibration values

Calibration value name	Description	Memory address
TS_CAL1	Temperature sensor ADC4 12-bit raw data acquired at (30 ± 5) °C, V_{DDA} = 3.0 V (± 10 mV)	0x0BFA 0710 - 0x0BFA 0711
TS_CAL2	Temperature sensor ADC4 12-bit raw data acquired at (130 ± 5) °C, V_{DDA} = 3.0 V (± 10 mV)	0x0BFA 0742 - 0x0BFA 0743

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3.20.2 Internal voltage reference (V_{REFINT})

The internal voltage reference voltage V_{REFINT} provides a stable (bandgap) voltage for the ADC and comparators. The V_{REFINT} is internally connected to ADC4 input channel that is used to convert the voltage into a digital value.

The precise voltage of VREFINT is individually measured for each part by STMicroelectronics during production test and stored in the system memory area. It is accessible in read-only mode.

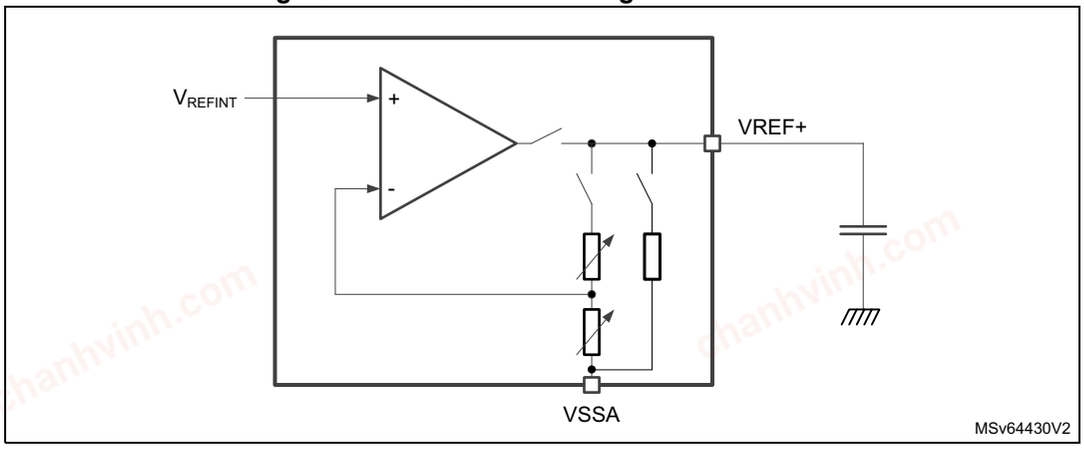
Table 15. Internal voltage reference calibration values

Calibration value name	Description	Memory address
VREFINT_CAL	Internal voltage reference ADC4 12-bit raw data acquired at (30 ± 5) °C, V_{DDA} = 3.0 V (± 10 mV)	0x0BFA 07A5 - 0x0BFA 07A6

3.21 Voltage reference buffer (VREFBUF)

The devices embed a voltage reference buffer (VREFBUF) that can be used as voltage reference for the ADC and external components through the VREF+ pin.

Figure 7. VREFBUF block diagram



The internal VREFBUF supports four voltages between 1.5 and 2.5 V, for more information see VREFBUF characteristics.

When the VREFBUF is disabled, an external voltage reference can be provided through the VREF+ pin.

3.22 Comparators (COMP)

The devices embed two rail-to-rail comparators, COMP1 and COMP2, with programmable reference voltage (internal or external), hysteresis and speed (low-speed for low-power) and with selectable output polarity.

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The reference voltage can be one of the following:

- internal reference voltage or sub-multiple (1/4, 1/2, 3/4).
- external reference voltage on GPIO in function COMPx_INM.

All comparators can wake up from Stop 0 and Stop 1 modes, generate interrupts and breaks for the timers and can also be combined into a window comparator.

3.23 Touch sensing controller (TSC)

The TSC (touch sensing controller) provides a simple solution to add capacitive sensing functionality to any application. A capacitive sensing technology is able to detect finger presence near an electrode that is protected from direct touch by a dielectric (glass, plastic or other). The capacitive variation introduced by the finger (or any conductive object) is measured using a proven implementation based on a surface charge transfer acquisition principle.

The TSC is fully supported by the STMTouch touch sensing firmware library that is free to use and allows touch sensing functionality to be implemented reliably in the end application.

The TSC main features are the following:

- Proven and robust surface charge transfer acquisition principle
- Support of up to 24 capacitive sensing channels
- Up to eight capacitive sensing channels can be acquired in parallel offering a very good response time
- Spread spectrum feature to improve system robustness in noisy environments
- Full hardware management of the charge transfer acquisition sequence
- Programmable charge transfer frequency
- Programmable sampling capacitor I/O pin
- Programmable channel I/O pin
- Programmable max count value to avoid long acquisition when a channel is faulty
- Dedicated end of acquisition and max count error flags with interrupt capability
- One sampling capacitor for up to three capacitive sensing channels to reduce the system components
- Compatible with proximity, touchkey, linear and rotary touch sensor implementation
- Designed to operate with STMTouch touch sensing firmware library

Note: The number of capacitive sensing channels is dependent on the packages and subject to I/O availability.

3.24 True random number generator (RNG)

The RNG is a true random number generator that provides full entropy outputs to the application as 32-bit samples. It is composed of a live entropy source (analog) and an internal conditioning component.

The RNG is a NIST SP 800-90B compliant entropy source that can be used to construct a nondeterministic random bit generator (NDRBG).

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The true random generator:

- Delivers 32-bit true random numbers, produced by an analog entropy source conditioned by a NIST SP800-90B approved conditioning stage
- Can be used as entropy source to construct a nondeterministic random bit generator (NDRBG)
- Produces four 32-bit random samples every 412 AHB clock cycles if f_{AHB} < 77 MHz (256 RNG clock cycles otherwise)
- Embeds start-up and NIST SP800-90B approved continuous health tests (repetition count and adaptive proportion tests), associated with specific error management
- Can be disabled to reduce power consumption, or enabled with an automatic low-power mode (default configuration)
- Has an AHB slave peripheral, accessible through 32-bit word single accesses only (else an AHB bus error is generated, and the write accesses are ignored)

3.25 Secure advanced encryption standard hardware accelerator (SAES) and encryption standard hardware accelerator (AES)

The devices embed two AES accelerators: SAES and AES. The SAES with hardware unique key embeds protection against differential power analysis (DPA) and related side channel attacks. The SAES can share its current key register information with the faster AES using a dedicated hardware bus.

The SAES and the AES can be used to both encrypt and decrypt data using the AES algorithm. It is a fully compliant implementation of the advanced encryption standard (AES) as defined by Federal Information Processing Standards Publication (FIPS PUB 197, Nov 2001).

Multiple chaining modes are supported for key sizes of 128 or 256 bits. ECB, CBC, CTR, CCM, GCM and GMAC chaining is supported by both SAES and AES.

SAES and AES support DMA single transfers for incoming and outgoing data (two DMA channels required).

The SAES supports the selection of all the following key sources, while the AES support only the first:

- 256-bit software key, written by the application in the key registers (write only)
- 256-bit DHUK (derived hardware unique key), computed inside the SAES engine from a nonvolatile OTP based RHUK (root hardware unique key)
- 256-bit BHK (boot hardware key), stored in tamper-resistant secure backup registers, written by a secure code during boot. Once written, this key cannot be read or write by any application until the next product reset.
- XOR of DHUK (provisioned chip secret) and BHK (software secret)

DHUK, BHK and their XOR are not visible by any software (even secure).

Note: 128-bit key size can also be selected.

BHK key is cleared in case of tamper or RDP regression.

When the SAES is secure (respectively nonsecure), DHUK secure (respectively nonsecure) is used.

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The SAES peripheral is connected by hardware to the true random number generator RNG (for side-channel resistance).

The SAES and AES peripherals support:

- Compliant implementation of standard NIST *Special Publication 197, Advanced Encryption Standard (AES)* and *Special Publication 800-38A, Recommendation for Block Cipher Modes of Operation*
- 128-bit data block processing
- Support for cipher keys length of 128- and 256-bit
- Encryption and decryption with multiple chaining modes:
  - Electronic codebook (ECB) mode
  - Cipher block chaining (CBC) mode
  - Counter (CTR) mode
  - Galois counter mode (GCM)
  - Galois message authentication code (GMAC) mode
  - Counter with CBC-MAC (CCM) mode
- 528 or 743 clock cycle latency in ECB encryption mode for SAES processing one 128-bit block of data with, respectively, 128- or 256-bit key
- 51 or 75 clock cycle latency in ECB encryption mode for AES processing one 128-bit block of data with, respectively, 128- or 256-bit key
- Integrated round key scheduler to compute the last round key for AES ECB/CBC decryption
- 256-bit register for storing the cryptographic key (four 32-bit registers), with key atomicity enforcement
- 128-bit registers for storing initialization vectors (four 32-bit registers)
- One 32-bit input buffer and one 32-bit output buffer
- Automatic data flow control with support of single-transfer direct memory access (DMA) using two channels (one for incoming data, one for processed data)
- Data swapping logic to support 1-, 8-, 16- or 32-bit data
- Possibility for software to suspend a message if the SAES/AES needs to process another message with a higher priority (suspend/resume operation)
- SAES additional features:
  - Security context enforcement for keys
  - Hardware secret key encryption/ decryption (wrapped key mode) and sharing with faster AES peripheral (Shared key mode)
  - Protection against DPA (differential power analysis) and related side-channel attacks
  - Optional hardware loading of two hardware secret keys (BHK, DHUK) that can be XORed together

On top of standard AES encryption and decryption with a key loaded by software, SAES peripheral makes possible the following advanced use cases:

- Allow or deny the sharing of a key between a secure and a nonsecure application, enforced by hardware
- Encrypt once a key using side-channel resistant AES, then share it to a faster AES engine by decrypting it (Shared key mode)
- On-chip encrypted storage using secret DHUK

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- Transport key generation by encrypting the device public unique ID with the application secret BHK
- Binding of device secure storage keys, using the secret derived hardware unique key (DHUK) XORed with the secret boot hardware key (BHK). If BHK is lost, the whole device secure storage is lost.

Note: Encrypted storage or derived keys that are using DHUK or BHK, cannot be used anymore when a security breach is detected.

Table 16. AES/SAES features

AES/SAES modes/features(1)	AES	SAES
ECB, CBC chaining	X	X
CTR, CCM, GCM chaining	X	X
AES 128-bit ECB encryption in cycles	51	528
DHUK and BHK key selection	-	X
Side-channel attacks resistance	-	X
Shared key between SAES and AES	X	

1. X = supported.

3.26 HASH hardware accelerator (HASH)

The HASH is a fully compliant implementation of the secure hash algorithm (SHA-1, SHA2-224, SHA-256), the MD5 (message-digest algorithm 5) hash algorithm and the keyed-hash message authentication code (HMAC) algorithm. HMAC is suitable for applications requiring message authentication.

The HASH computes Federal information processing standards (FIPS) approved digests of length of 160, 224, 256 bits, for messages of up to (2^{64} – 1) bits. It also computes 128 bits digests for the MD5 algorithm.

The HASH main features are:

- Suitable for data authentication applications, compliant with:
  - Federal Information Processing Standards Publication FIPS PUB 180-4, *Secure Hash Standard* (SHA-1 and SHA-2 family)
  - Federal Information Processing Standards Publication FIPS PUB 186-4, *Digital* Signature Standard (DSS)
  - Internet Engineering Task Force (IETF) Request For Comments RFC 1321, *MD5* Message-Digest Algorithm
  - Internet Engineering Task Force (IETF) Request For Comments RFC 2104, *HMAC: Keyed-Hashing for Message Authentication* and Federal Information Processing Standards Publication FIPS PUB 198-1, *The Keyed-Hash Message* Authentication Code (HMAC)
- Fast computation of SHA-1, SHA2-224, SHA-256, and MD5
  - 82 (respectively 66) clock cycles for processing one 512-bit block of data using SHA-1 (respectively SHA-256) algorithm
  - 66 clock cycles for processing one 512-bit block of data using MD5 algorithm

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- Corresponding 32-bit words of the digest from consecutive message blocks are added to each other to form the digest of the whole message
  - Automatic 32-bit words swapping to comply with the internal little-endian representation of the input bit string
  - Word swapping supported: bits, bytes, half-words and 32-bit words
- Automatic padding to complete the input bit string to fit digest minimum block size of 512 bits (16 × 32 bits)
- Single 32-bit input register associated to an internal input FIFO of sixteen 32-bit words, corresponding to one block size
- AHB slave peripheral, accessible through 32-bit word accesses only (else an AHB error is generated)
- 8 × 32-bit words (H0 to H7) for output message digest
- Automatic data flow control with support of direct memory access (DMA) using one channel. Single or fixed burst of 4 supported.
- Interruptible message digest computation, on a per-32-bit word basis
  - Re-loadable digest registers
  - Hashing computation suspend/resume mechanism, including using DMA

3.27 Public key accelerator (PKA)

The PKA is intended for the computation of cryptographic public key primitives, specifically those related to RSA, DU (Diffie-Hellmann) or (ECC) elliptic curve cryptography over GF(p) (Galois fields). To achieve high performance at a reasonable cost, these operations are executed in the Montgomery domain.

All needed computations are performed within the accelerator, so no further hardware/software elaboration is needed to process the inputs or the outputs.

The PKA main features are:

- Acceleration of RSA, DH and ECC over GF(p) operations, based on the Montgomery method for fast modular multiplications. More specifically:
  - RSA modular exponentiation, RSA CRT (Chinese remainder theorem) exponentiation
  - ECC scalar multiplication, point on curve check, complete addition, double base ladder, projective to affine
  - ECDSA signature generation and verification
- Capability to handle operands up to 4160 bits for RSA/DH and 640 bits for ECC
- Arithmetic and modular operations such as addition, subtraction, multiplication, modular reduction, modular inversion, comparison, and Montgomery multiplication
- Built-in Montgomery domain inward and outward transformations
- Protection against DPA (differential power analysis) and related side-channel attacks.

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3.28 Timers and watchdogs

The devices include one advanced control timer, up to five general-purpose timers, two low-power timers, two watchdog timers and two SysTick timers.

Table 17 compares the features of the advanced control, general-purpose and basic timers.

Table 17. Timer feature comparison

Timer type	Timer	Counter resolution	Counter type	Prescaler factor	DMA request generation	Capture/ compare channels	Complementary outputs
Advanced control	TIM1	16 bits	Up, down, Up/down	Any integer between 1 and 65536	Yes	4	3
General-purpose	TIM2, TIM4	32 bits	Up, down, Up/down			4	No
	TIM3,	16 bits				4	No
	TIM16, TIM17		Up			1	1

3.28.1 Advanced-control timers (TIM1)

The advanced-control timers can each be seen as a three-phase PWM multiplexed on six channels. They have complementary PWM outputs with programmable inserted dead-times. They can also be seen as complete general-purpose timers.

The four independent channels can be used for:

- Input capture
- Output compare
- PWM generation (edge- or center-aligned modes) with full modulation capability (0 - 100%)
- One-pulse mode output

In Debug mode, the advanced-control timer counter can be frozen and the PWM outputs disabled in order to turn off any power switches driven by these outputs.

Many features are shared with the general-purpose TIMx timers (described in the next section) using the same architecture, so the advanced-control timers can work together with the TIMx timers via the *Timer Link* feature for synchronization or event chaining.

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3.28.2 General-purpose timers (TIM2, TIM3, TIM4, TIM16, TIM17)

There are up to five synchronizable general-purpose timers embedded in the device (see *Table 17* for differences). Each general-purpose timer can be used to generate PWM outputs, or act as a simple time base.

- TIM2, TIM3 and TIM4
  - They are full-featured general-purpose timers with TIM2 and TIM4 32-bit auto-reload up/downcounter, TIM3 16-bit auto-reload up/downcounter, all with 16-bit prescaler.
  - These timers feature four independent channels for input capture/output compare, PWM or one-pulse mode output. They can work together, or with the other general-purpose timers via the *Timer Link* feature for synchronization or event chaining.
  - The counters can be frozen in Debug mode.
  - All have independent DMA request generation and support quadrature encoders.
- TIM16 and 17
  - They are general-purpose timers with mid-range features.
  - They have 16-bit auto-reload upcounters and 16-bit prescalers. and have one channel and one complementary channel.
  - All channels can be used for input capture/output compare, PWM or one-pulse mode output.
  - The timers can work together via the *Timer Link* feature for synchronization or event chaining. The timers have independent DMA request generation.
  - The counters can be frozen in Debug mode.
  - All have independent DMA request generation.

3.28.3 Low-power timers (LPTIM1, LPTIM2)

The devices embed two low-power timers. These timers have an independent clock and are running in Stop mode if they are clocked by HSI16, LSE, LSI or an external clock. They are able to wake up the system from Stop mode.

LPTIM1, LPTIM2 are active in Stop modes. Only LPTIM1 is active in Stop 2 mode.

The low-power timer supports the following features:

- 16-bit up counter with 16-bit autoreload register
- 3-bit prescaler with following possible dividing factors (1, 2, 4, 8, 16, 32, 64, 128)
- Selectable clock
  - Internal clock sources: LSE, LSI, HSI16 or APB clock
  - External clock source over LPTIM input (working with no LP oscillator running, used by *Pulse Counter* application)
- 16-bit ARR autoreload register
- 16-bit capture/compare register
- Continuous/One-shot mode
- Selectable software/hardware input trigger
- Programmable digital glitch filter
- Configurable output: pulse, PWM
- Configurable I/O polarity

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- Encoder mode
- Repetition counter
- Up to two independent channels for:
  - Input capture
  - PWM generation (edge-aligned mode)
  - One-pulse mode output
- Interrupt generation on ten events
- DMA request generation on the following events:
  - Update event
  - Input capture

3.28.4 Infrared interface (IRTIM)

An infrared interface (IRTIM) for remote control is available on the device. It can be used with an infrared LED to perform remote control functions. It uses internal connections with TIM16 and TIM17.

3.28.5 Independent watchdog (IWDG)

The independent watchdog is based on a 12-bit downcounter and a 10-bit prescaler. It is clocked from the independent LSI and, as it operates independently from the main clock, it can operate in Stop and Standby modes. It can be used either as a watchdog to reset the device when a problem occurs, or as a free running timer for application timeout management. It is hardware or software enabled through the option bytes. The counter can be frozen in low-power and Debug mode.

3.28.6 Window watchdog (WWDG)

The window watchdog is based on a 7-bit downcounter that can be set as free running. It can be used as a watchdog to reset the device when a problem occurs. It is clocked from the main clock. It has an early warning interrupt capability and the counter can be frozen in Debug mode.

3.28.7 SysTick timer

The Cortex-M33 with TrustZone embeds two SysTick timers.

When TrustZone is activated, two SysTick timer are available:

- SysTick, secure instance
- SysTick, nonsecure instance

When TrustZone is disabled, only one SysTick timer is available.

This timer (secure or nonsecure) is dedicated to real-time operating systems, but can also be used as a standard down counter. It features:

- A 24-bit down counter
- Autoreload capability
- Maskable system interrupt generation when the counter reaches 0
- Programmable clock source

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3.29 Real-time clock (RTC)

The real-time clock (RTC) is an independent BCD timer/counter. The RTC provides a time-of-day clock/calendar with programmable alarm interrupts.

As long as the VDD supply voltage remains in the operating range, the RTC never stops, regardless of the device status (Run mode, low-power mode or under reset).

The RTC supports the following features:

- Calendar with subsecond, seconds, minutes, hours (12 or 24 format), weekday, date, month, year, in binary-coded decimal (BCD) format
- Binary mode with 32-bit free-running counter
- Automatic correction for 28, 29 (leap year), 30, and 31 days of the month
- Two programmable alarms
- On-the-fly correction from 1 to 32767 RTC clock pulses. This can be used to synchronize it with a reference clock
- Reference clock detection: a more precise second source clock (50 or 60 Hz) can be used to enhance the calendar precision
- Digital calibration circuit with 0.95 ppm resolution, to compensate for quartz crystal inaccuracy
- Timestamp feature that can be used to save the calendar content. This function can be triggered by an event on the timestamp pin, or by a tamper event
- 17-bit auto-reload wake-up timer (WUT) for periodic events with programmable resolution and period
- TrustZone support:
  - RTC fully securable
  - Alarm A, alarm B, wake-up timer and timestamp individual secure or nonsecure configuration
  - Alarm A, alarm B, wake-up timer and timestamp individual privileged protection

The RTC is supplied from the V_{DD} supply.

The RTC clock sources can be one of the following:

- LSE, used as 32.768 kHz external crystal oscillator
- LSE, with external resonator or oscillator
- LSI, internal low-power RC oscillator (with typical frequency of 32 kHz)
- HSE32, high-speed external clock divided by a prescaler in the RCC.

The RTC is functional in all low-power modes when it is clocked by the LSE or LSI.

All RTC events (alarm, wake-up timer, timestamp) can generate an interrupt and wake up the device from the low-power modes.

3.30 Tamper and backup registers (TAMP)

The anti-tamper detection circuit is used to protect sensitive data from external attacks. 32 32-bit backup registers are retained in all low-power modes. The backup registers, as well as other secrets in the device, are protected by this anti-tamper detection circuit with six tamper pins and nine internal tampers. The external tamper pins can be configured for level

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detection with or without filtering, or active tamper that increases the security level by auto checking that the tamper pins are not externally opened or shorted.

TAMP main features:

- A tamper detection can erase the backup registers, SRAM2, ICACHE and cryptographic peripherals.
- 32 32-bit backup registers:
  - The backup registers (TAMP_BKPxR) are implemented in the Backup domain that remains powered-on by V_{DD} power.
- Up to six tamper pins for six external tamper detection events:
  - Active tamper mode: continuous comparison between tamper output and input to protect from physical open-short attacks
  - Flexible active tamper I/O management: from three meshes (each input associated to its own exclusive output) to five meshes (single output shared for up to five tamper inputs)
  - Passive tampers: ultra-low-power edge or level detection with internal pull-up hardware management
  - Configurable digital filter
- Nine internal tamper events to protect against transient or environmental perturbation attacks:
  - LSE monitoring
  - RTC calendar overflow
  - JTAG/SWD access if RDP different from 0
  - Monotonic counter overflow
  - Cryptographic peripherals fault (RNG, SAES, AES, PKA)
  - Independent watchdog reset when tamper flag is already set
  - Three ADC4 watchdogs
- Each tamper can be configured in two modes:
  - Hardware mode: immediate erase of secrets on tamper detection, including backup registers erase
  - Software mode: erase of secrets following a tamper detection launched by software
- Any tamper detection can generate a RTC time stamp event.
- TrustZone support:
  - Tamper secure or nonsecure configuration.
  - Backup registers configuration in three configurable-size areas:
    - a read/write secure area
    - a write secure/read nonsecure area
    - a read/write nonsecure area
  - Secret boot hardware key (BHK) only usable by secure SAES peripheral, stored in backup registers, protected against read and write access
- Tamper configuration and backup registers privilege protection
- Monotonic counter

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3.31 Inter-integrated circuit interface (I2C)

The device embeds up to four I2C, refer to *Table 18* for the features implementation.

The I^2C bus interface handles communications between the microcontroller and the serial I^2C bus. It controls all I^2C bus-specific sequencing, protocol, arbitration and timing.

The I2C peripheral supports:

- I^2C-bus specification and user manual rev. 5 compatibility:
  - Controller and target modes, multicontroller capability
  - Standard-mode (Sm), with a bit rate up to 100 Kbit/s
  - Fast-mode (Fm), with a bit rate up to 400 Kbit/s
  - Fast-mode Plus (Fm+), with a bit rate up to 1 Mbit/s and 20 mA output drive I/Os
  - 7-bit and 10-bit addressing mode, multiple 7-bit slave addresses
  - Programmable setup and hold times
  - Optional clock stretching
- System management bus (SMBus) specification rev 3.0 compatibility:
  - Hardware packet error checking (PEC) generation and verification with ACK control
  - Address resolution protocol (ARP) support
  - SMBus alert
- Power system management protocol (PMBus) specification rev 1.3 compatibility
- Independent clock: a choice of independent clock sources allowing the I2C communication speed to be independent from the PCLK reprogramming
- Autonomous functionality in Stop modes with wake-up from Stop capability
- Programmable analog and digital noise filters
- 1-byte buffer with DMA capability

Table 18. I2C implementation

I2C features(1)	I2C1	I2C2	I2C3	I2C4
Standard-mode (up to 100 Kbit/s)	X	X	X	X
Fast-mode (up to 400 Kbit/s)	X	X	X	X
Fast-mode Plus with 20 mA output drive I/Os (up to 1 Mbit/s)	X	X	X	X
Programmable analog and digital noise filters	X	X	X	X
SMBus/PMBus hardware support	X	X	X	X
Independent clock	X	X	X	X
Autonomous in Stop 0, 1 modes with wake-up capability	X	X	X	X
Wake-up capability in Stop 2 mode	-	-	X	-

1. X: supported

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3.32 Universal synchronous/asynchronous receiver transmitter (USART) and low-power universal asynchronous receiver transmitter (LPUART)

The devices have up to three embedded universal synchronous receiver transmitters (USART1, USART2, USART3) and one low-power universal asynchronous receiver transmitter (LPUART1).

Table 19. USART and LPUART features

USART modes/features(1)	USART1	USART2	USART3	LPUART1
Hardware flow control for modem	X	X	X	X
Continuous communication using DMA	X	X	X	X
Multiprocessor communication	X	X	X	X
Synchronous mode (master/slave)	X	X	X	-
Smartcard mode	X	X	X	-
Single-wire half-duplex communication	X	X	X	X
IrDA SIR ENDEC block	X	X	X	-
LIN mode	X	X	X	-
Dual-clock domain, wake-up from Stop modes	X	X	X	X
Dual-clock domain, wake-up from Stop 2 modes	-	-	-	X
Receiver timeout interrupt	X	X	X	-
Modbus communication	X	X	X	-
Auto-baud rate detection	X	X	X	-
Driver enable	X	X	X	X
USART data length	7, 8, and 9 bits			
Tx/Rx FIFO	X	X	X	X
Tx/Rx FIFO size	8 bytes			
Autonomous in Stop 0, 1 modes with wake-up capability	X	X	X	X
Wake-up capability in Stop 2 mode	-	-	-	X

1. X = supported.

3.32.1 USART

The USART offers a flexible means to perform full-duplex data exchange with external equipments requiring an industry standard NRZ asynchronous serial data format. A very wide range of baud rates can be achieved through a fractional baud rate generator.

The USART supports both synchronous one-way and half-duplex single-wire communications, as well as LIN (local interconnection network), Smartcard protocol, IrDA (infrared data association) SIR ENDEC specifications, and modem operations (CTS/RTS). Multiprocessor communications are also supported.

High-speed data communications up to 20 Mbauds are possible by using the direct memory access (DMA) for multibuffer configuration.

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The USART main features are:

- Full-duplex asynchronous communication
- NRZ standard format (mark/space)
- Configurable oversampling method by 16 or 8 to achieve the best compromise between speed and clock tolerance
- Baud rate generator systems
- Two internal FIFOs for transmit and receive data
  Each FIFO can be enabled/disabled by software and come with a status flag.
- A common programmable transmit and receive baud rate
- Dual-clock domain with dedicated kernel clock for peripherals independent from PCLK
- Auto baud rate detection
- Programmable data word length (7, 8 or 9 bits)
- Programmable data order with MSB-first or LSB-first shifting
- Configurable stop bits (1 or 2 stop bits)
- Synchronous Master/Slave mode and clock output/input for synchronous communications
- SPI slave transmission underrun error flag
- Single-wire half-duplex communications
- Continuous communications using DMA
- Received/transmitted bytes are buffered in reserved SRAM using centralized DMA
- Separate enable bits for transmitter and receiver
- Separate signal polarity control for transmission and reception
- Swappable Tx/Rx pin configuration
- Hardware flow control for modem and RS-485 transceiver
- Communication control/error detection flags
- Parity control:
  - Transmits parity bit
  - Checks parity of received data byte
- Interrupt sources with flags
- Multiprocessor communications: wake-up from Mute mode by idle line detection or address mark detection
- Autonomous functionality in Stop mode with wake-up from stop capability
- LIN master synchronous break send capability and LIN slave break detection capability
  - 13-bit break generation and 10/11-bit break detection when USART is hardware configured for LIN
- IrDA SIR encoder decoder supporting 3/16-bit duration for Normal mode
- Smartcard mode
  - Supports the T = 0 and T = 1 asynchronous protocols for smartcards as defined in the ISO/IEC 7816-3 standard
  - 0.5 and 1.5 stop bits for Smartcard operation
- Support for Modbus communication
  - Timeout feature
  - CR/LF character recognition

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3.32.2 LPUART

The LPUART supports bidirectional asynchronous serial communication with minimum power consumption. It also supports half-duplex single-wire communication and modem operations (CTS/RTS). It allows multiprocessor communication.

Only a 32.768 kHz clock (LSE) is needed to allow LPUART communication up to 9600 baud. Therefore, even in Stop mode, the LPUART can wait for an incoming frame while having an extremely low energy consumption. Higher-speed clock can be used to reach higher baudrates.

The LPUART interface can be served by the DMA controller.

The LPUART main features are:

- Full-duplex asynchronous communications
- NRZ standard format (mark/space)
- Programmable baud rate
- From 300 to 9600 baud/s using a 32.768 kHz clock source
- Higher baud rates can be achieved by using a higher frequency clock source
- Two internal FIFOs to transmit and receive data (each FIFO can be enabled/disabled by software and come with status flags for FIFOs states)
- Dual-clock domain with dedicated kernel clock for peripherals independent from PCLK
- Programmable data word length (7 or 8 or 9 bits)
- Programmable data order with MSB-first or LSB-first shifting
- Configurable stop bits (1 or 2 stop bits)
- Single-wire half-duplex communications
- Continuous communications using DMA
- Received/transmitted bytes are buffered in reserved SRAM using centralized DMA
- Separate enable bits for transmitter and receiver
- Separate signal polarity control for transmission and reception
- Swappable Tx/Rx pin configuration
- Hardware flow control for modem and RS-485 transceiver
- Transfer detection flags:
  - Receive buffer full
  - Transmit buffer empty
  - Busy and end of transmission flags
- Parity control:
  - Transmits parity bit
  - Checks parity of received data byte
- Four error detection flags:
  - Overrun error
  - Noise detection
  - Frame error
  - Parity error
- Interrupt sources with flags

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- Multiprocessor communications: wake-up from Mute mode by idle line detection or address mark detection
- Autonomous functionality in Stop modes with wake-up.

3.33 Serial peripheral interface (SPI)

The devices embed up to three serial peripheral interfaces (SPI) that can be used to communicate with external devices while using the specific synchronous protocol. The SPI protocol supports half-duplex, full-duplex and simplex synchronous, serial communication with external devices.

The interface can be configured as master or slave and can operate in multislave or multimaster configurations. The device configured as master provides communication clock (SCK) to the slave device. The slave select (SS) and ready (RDY) signals can be applied optionally just to setup communication with concrete slave and to assure it handles the data flow properly. The Motorola data format is used by default, but some other specific modes are supported as well.

The SPI main features are:

- Full-duplex synchronous transfers on three lines
- Half-duplex synchronous transfer on two lines (with bidirectional data line)
- Simplex synchronous transfers on two lines (with unidirectional data line)
- 4-bit to 32-bit data size selection or fixed to 8-bit and 16-bit only
- Multimaster or multislave mode capability
- Dual-clock domain, separated clock for the peripheral kernel that can be independent of PCLK
- Baud rate prescaler up to kernel frequency/2 or bypass from RCC in master mode
- Protection of configuration and setting
- Hardware or software management of SS for both master and slave
- Adjustable minimum delays between data and between SS and data flow
- Configurable SS signal polarity and timing, MISO and MOSI swap capability
- Programmable clock polarity and phase
- Programmable data order with MSB-first or LSB-first shifting
- Programmable number of data within a transaction to control SS and CRC
- Dedicated transmission and reception flags with interrupt capability
- SPI Motorola and TI formats support
- Hardware CRC feature can secure communication at the end of transaction by:
  - Adding CRC value in Tx mode
  - Automatic CRC error checking for Rx mode
- Error detection with interrupt capability in case of data overrun, CRC error, data underrun at slave, mode fault at master
- Two 16 x or 8 x 8-bit embedded Rx and TxFIFOs with DMA capability
- Programmable number of data in transaction
- Configurable FIFO thresholds (data packing)
- Configurable behavior at slave underrun condition (support of cascaded circular buffers)

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- Autonomous functionality in Stop modes (handling of the transaction flow and required clock distribution) with wake-up from stop capability
- Optional status pin RDY signalizing the slave device ready to handle the data flow.

Table 20. SPI features

Feature[1]	SPI1, SPI2 (full feature set instances)	SPI3 (limited feature set instance)
Data size	Configurable from 4- to 32-bit	8- and 16-bit
CRC computation	CRC polynomial length, configurable from 5- to 33-bit	CRC polynomial length, configurable from 9- to 17-bit
Size of FIFOs	16 x 8-bit	8 x 8-bit
Number of transfered data	Unlimited, expandable	Up to 1024, no data counter
Autonomous in Stop 0, 1 modes with wake-up capability	X	X
Wake-up capability in Stop 2 mode	-	X

1. X: supported

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3.34 Serial audio interfaces (SAI)

The devices embed one SAI, see *Table 21* for its features. The SAI bus interface handles communications between the microcontroller and the serial audio protocol.

The SAI peripheral supports:

- Two independent audio sub-blocks that can be transmitters or receivers with their respective FIFOs
- 8-word integrated FIFOs for each audio sub-block
- Synchronous or Asynchronous mode between the audio sub-blocks
- Master or slave configuration independent for both audio sub-blocks
- Clock generator for each audio block to target independent audio frequency sampling when both audio sub-blocks are configured in master mode
- Data size configurable: 8-, 10-, 16-, 20-, 24- and 32-bit
- Peripheral with large configurability and flexibility allowing to target as example the following audio protocol: I^2S, LSB or MSB-justified, PCM/DSP, TDM, AC'97 and SPDIF out
- Up to 16 slots available with configurable size and with the possibility to select which ones are active in the audio frame
- Number of bits by frame may be configurable
- Frame synchronization active level configurable (offset, bit length, level)
- First active bit position in the slot is configurable
- LSB first or MSB first for data transfer
- Mute mode
- Stereo/mono audio frame capability
- Communication clock strobing edge configurable (SCK)
- Error flags with associated interrupts if enabled respectively
  - Overrun and underrun detection
  - Anticipated frame synchronization signal detection in Slave mode
  - Late frame synchronization signal detection in Slave mode
  - Codec not ready for the AC'97 mode in reception
- Interruption sources when enabled:
  - Errors
  - FIFO requests
- DMA interface with two dedicated channels to handle access to the dedicated integrated FIFO of each SAI audio sub-block

Table 21. SAI implementation

Features	SAI1
I^2S, LSB or MSB-justified, PCM/DSP, TDM, AC'97	X
Mute mode	X
Stereo/mono audio frame capability	X
16 slots	X
Data size configurable: 8-, 10-, 16-, 20-, 24-, and 32-bit	X

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Table 21. SAI implementation (continued)

Features	SAI1
FIFO size	X (8 words)
SPDIF	X
PDM	X

3.35 USB on-the-go high-speed (USB OTG)

The devices embed an USB OTG high-speed device/host peripheral with integrated transceivers. This peripheral is compliant with the USB 2.0 specification. It has software-configurable endpoint setting, and supports suspend/resume.

This interface requires a precise 60 MHz clock that is generated from the internal USB OTG HS PHY PLL (the clock source must use the HSE crystal oscillator).

The USB OTG HS features are:

- USB-IF certified to the Universal Serial Bus Specification Rev 2.0
- On-chip high-speed PHY
- Full support (PHY)
  - Integrated support for A-B device identification (ID line)
  - Supports monitoring of V_{BUS} levels with internal comparators
- Software-configurable to operate as USB high-speed device/host role device
- Supports HS/FS SOF and LS keep-alives with
  - SOF pulse PAD connectivity
  - SOF pulse internal connection to timer (TIMx)
  - Configurable framing period
  - Configurable end of frame interrupt
- Internal DMA with thresholding support and software selectable AHB burst type in DMA mode
- Power saving features, such as system stop during USB OTG suspend, switch-off of clock domains internal to the digital core, PHY and DFIFO power management
- Dedicated RAM of 4 Kbytes with advanced FIFO control:
  - Configurable partitioning of RAM space into different FIFOs for flexible and efficient use of RAM
  - Each FIFO able to hold multiple packets
  - Dynamic memory allocation
  - Configurable FIFO sizes that are not powers of two to allow the use of contiguous memory locations
- Max guaranteed USB bandwidth for up to one frame (1 ms) without system intervention

Host-mode features:

- External charge pump for V_{BUS} voltage generation
- Up to 16 host channels (pipes): each channel is dynamically reconfigurable to allocate any type of USB transfer
- Built-in hardware scheduler holding:

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  - Up to 16 interrupt plus isochronous transfer requests in the periodic hardware queue
  - Up to 16 control plus bulk transfer requests in the nonperiodic hardware queue
- Management of a shared Rx FIFO, a periodic Tx FIFO and a nonperiodic Tx FIFO for efficient usage of the USB data RAM

Peripheral-mode features:

- 1 bidirectional control endpoint0
- 8 IN endpoints (EPs) configurable to support bulk, interrupt or isochronous transfers
- 8 OUT endpoints configurable to support bulk, interrupt or isochronous transfers
- Management of a shared Rx FIFO and a Tx-OUT FIFO for efficient usage of the USB data RAM
- Management of up to 9 dedicated Tx-IN FIFOs (one for each active IN EP) to put less load on the application
- Support for the soft disconnect feature

3.36 Development support

3.36.1 Serial-wire/JTAG debug port (SWJ-DP)

The Arm SWJ-DP interface is embedded and is a combined JTAG and serial-wire debug port that enables either a serial wire debug or a JTAG probe to be connected to the target.

Debug is performed using two pins only instead of five required by the JTAG (JTAG pins can be re-used as GPIO with alternate function): the JTAG TMS and TCK pins are shared with SWDIO and SWCLK, respectively, and a specific sequence on the TMS pin is used to switch between JTAG-DP and SW-DP.

3.36.2 Embedded Trace Macrocell (ETM)

The Arm embedded trace macrocell (ETM) provides a greater visibility of the instruction and data flow inside the CPU core by streaming compressed data at a very high rate from the device through a small number of ETM pins to an external hardware trace port analyzer (TPA) device.

Real-time instruction and data flow activity is recorded and then formatted for display on the host computer that runs the debugger software. PTA hardware is commercially available from common development tools vendors.

The ETM operates with third party debugger software tools.

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4 Pinout, pin description, and alternate functions

4.1 Pinout/ballout schematics

Figure 8. UFQFPN48_USB pinout

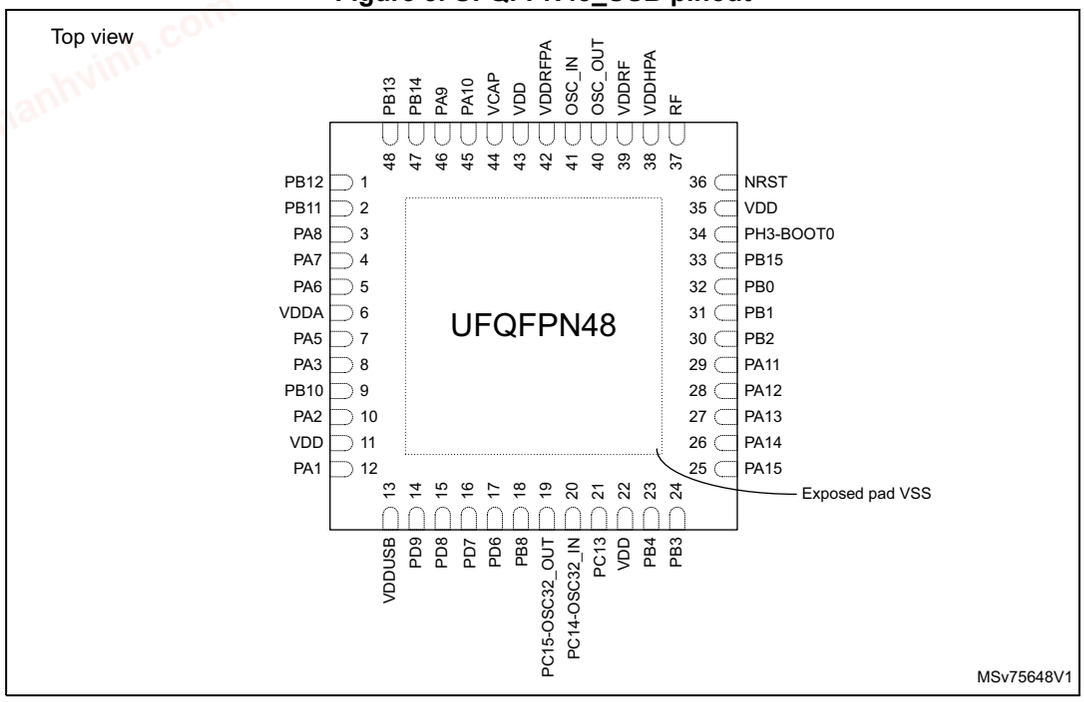
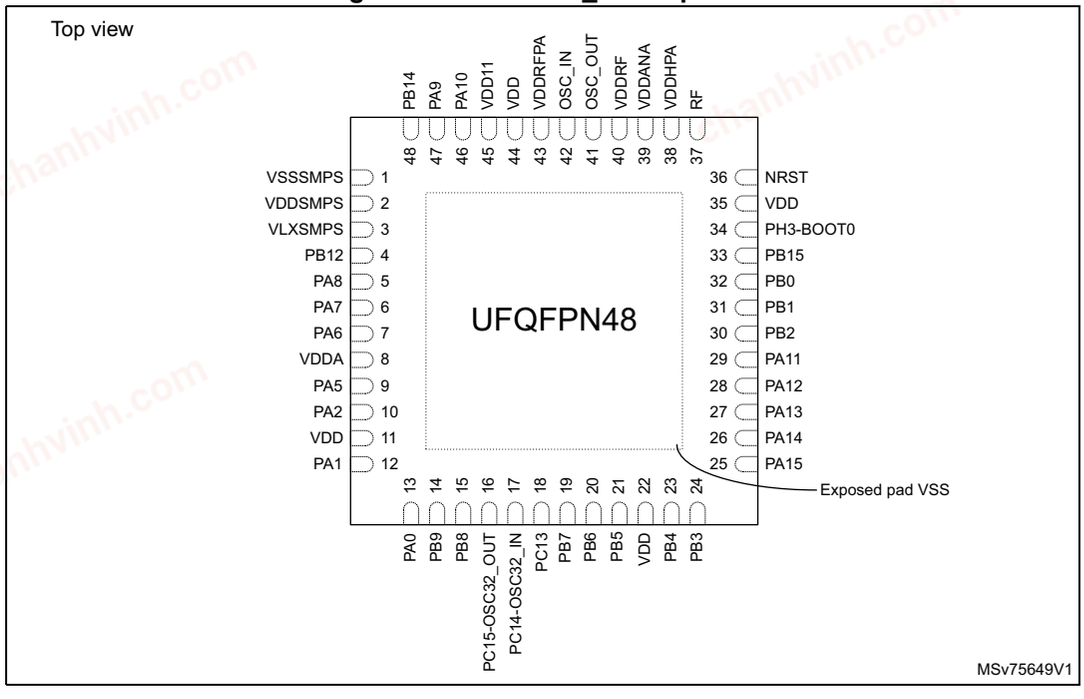


Figure 9. UFQFPN48_SMPS pinout



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Figure 10. UFQFPN48_SMPS_USB pinout

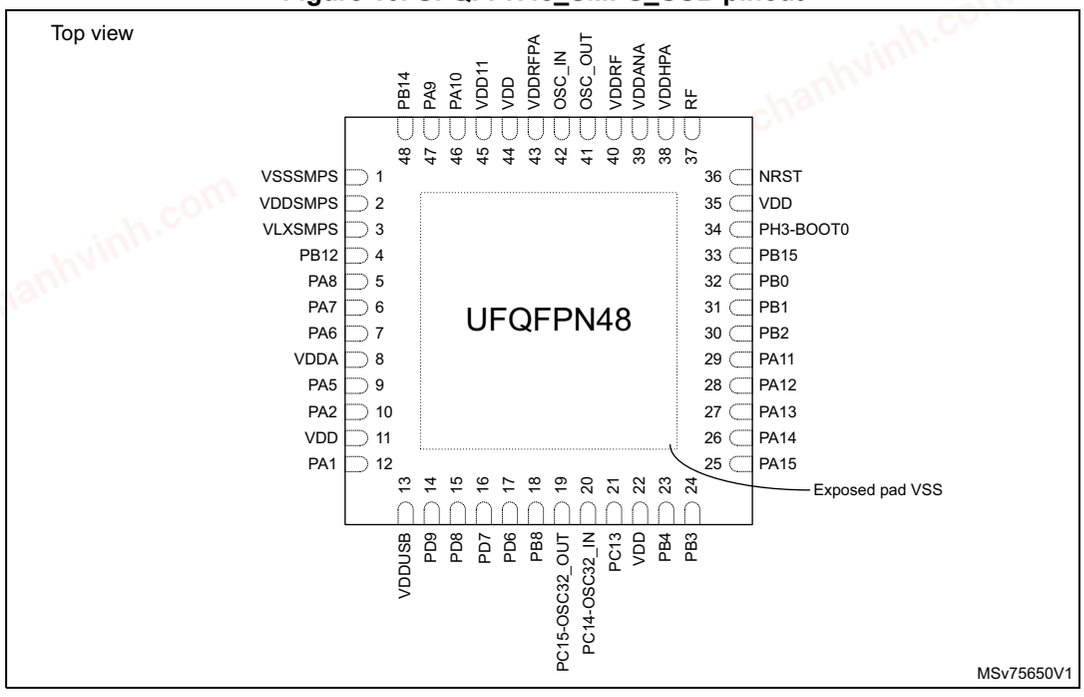
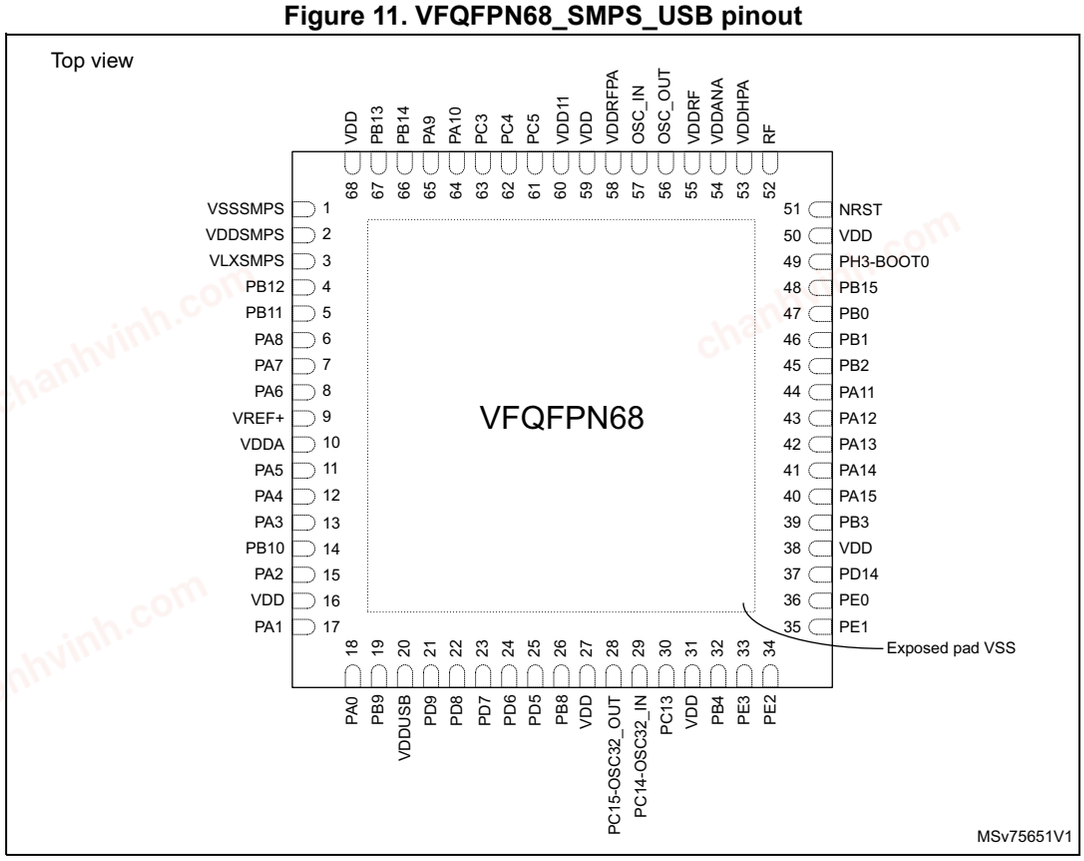
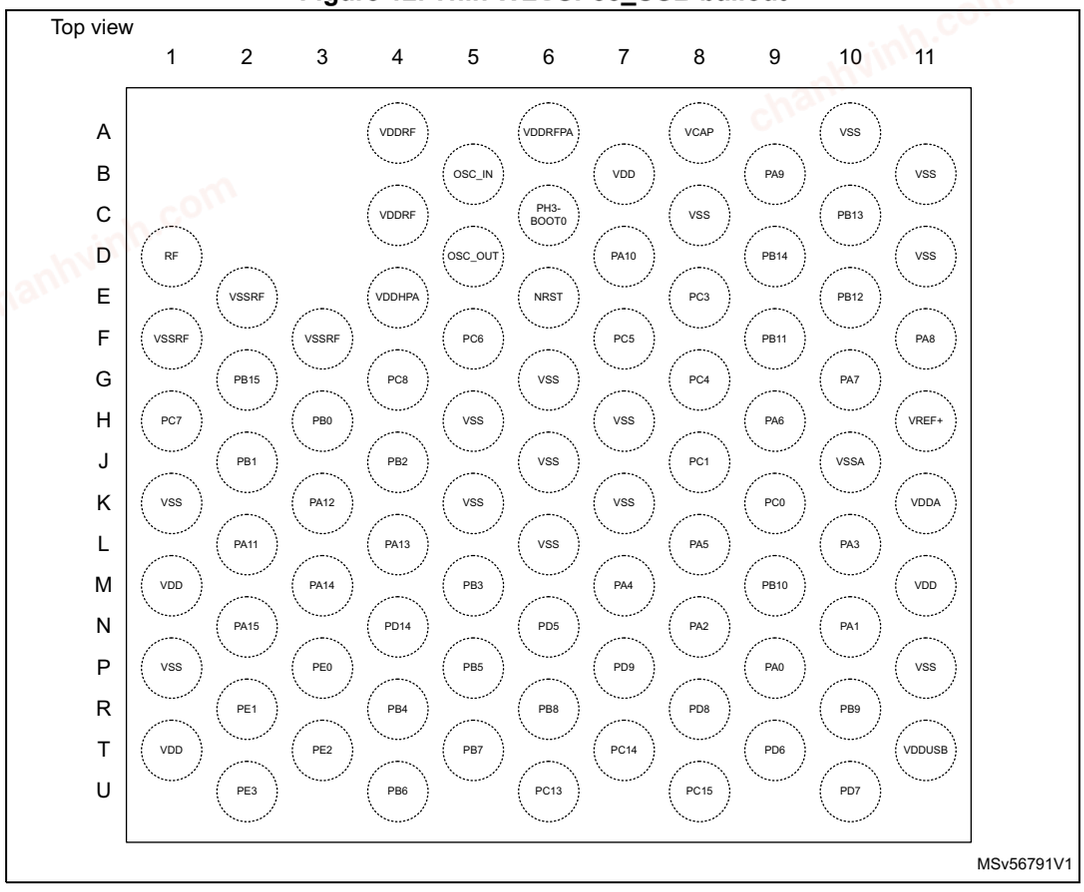


Figure 11. VFQFPN68_SMPS_USB pinout



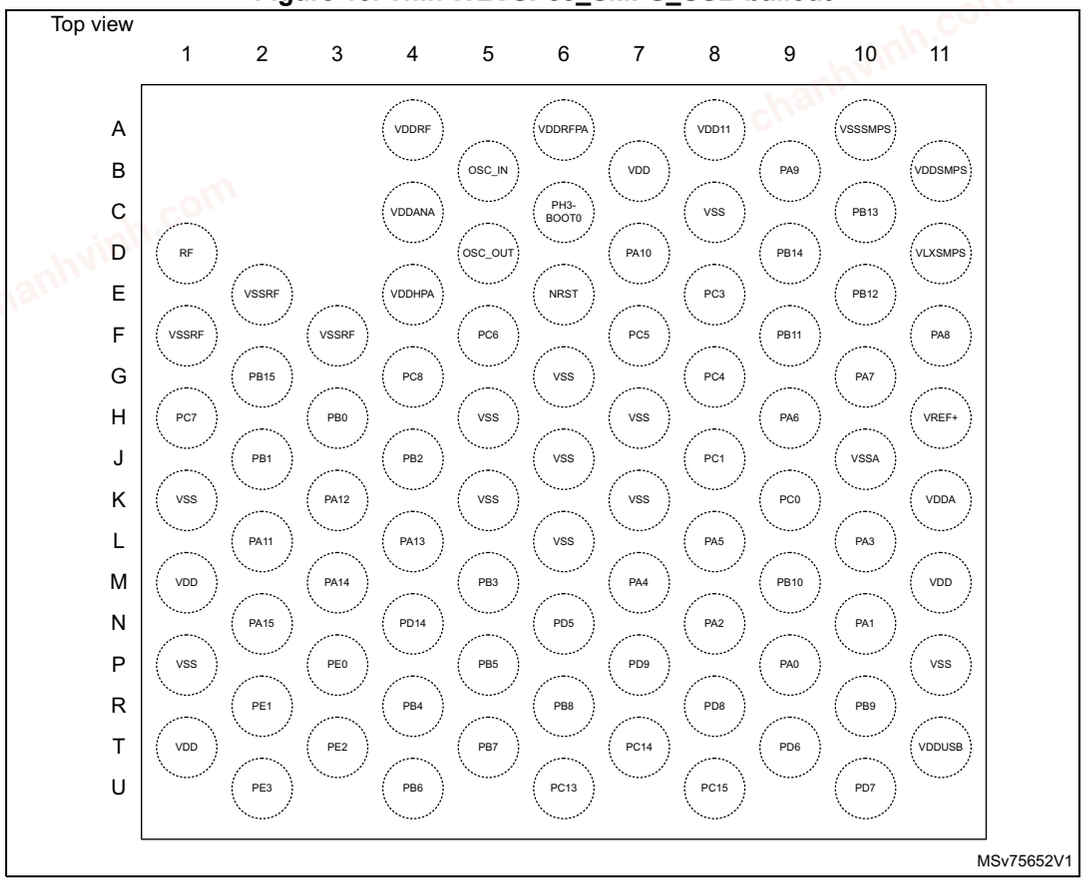
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Figure 12. Thin WLCSP88_USB ballout



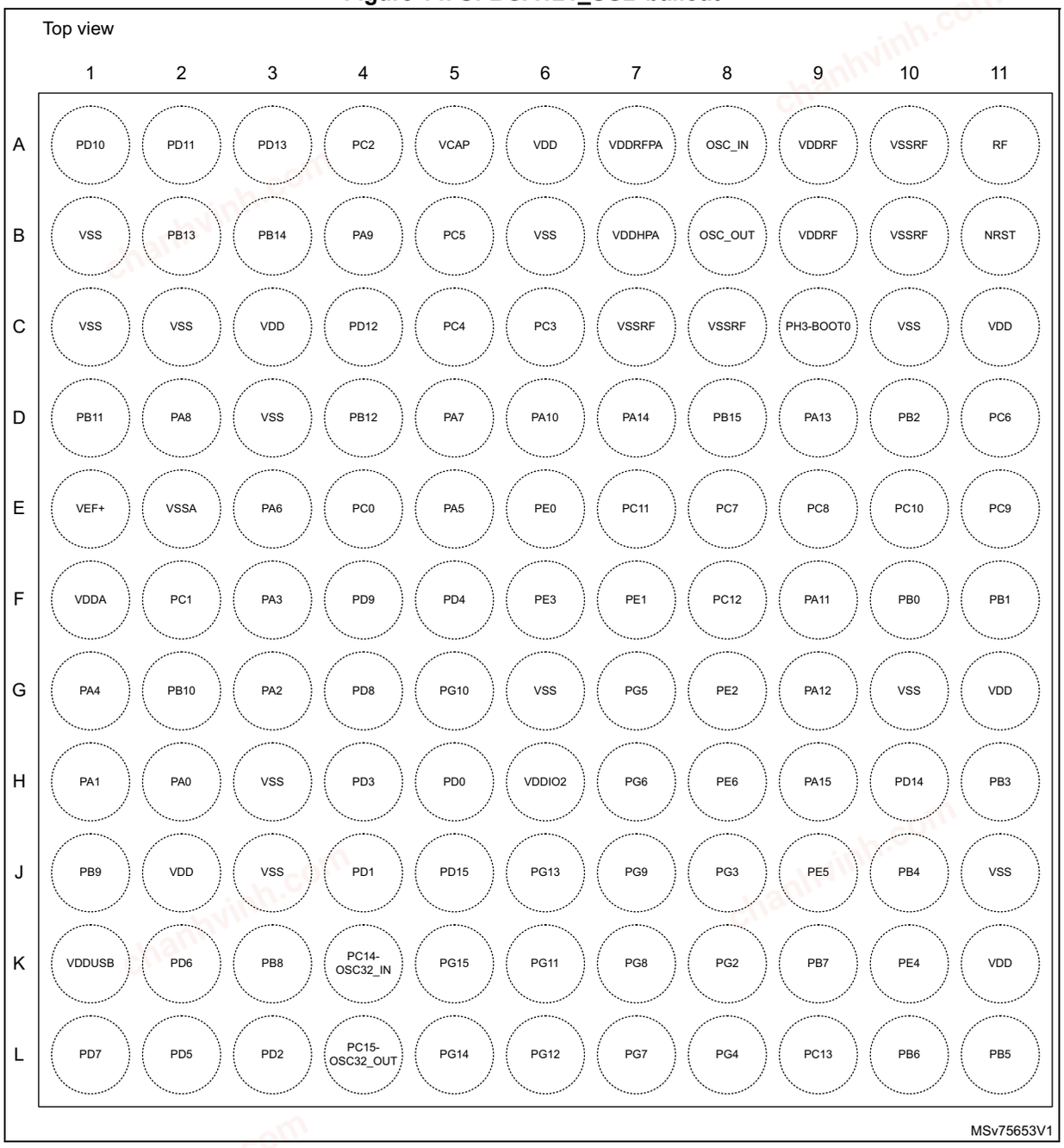
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Figure 13. Thin WLCSP88_SMPS_USB ballout



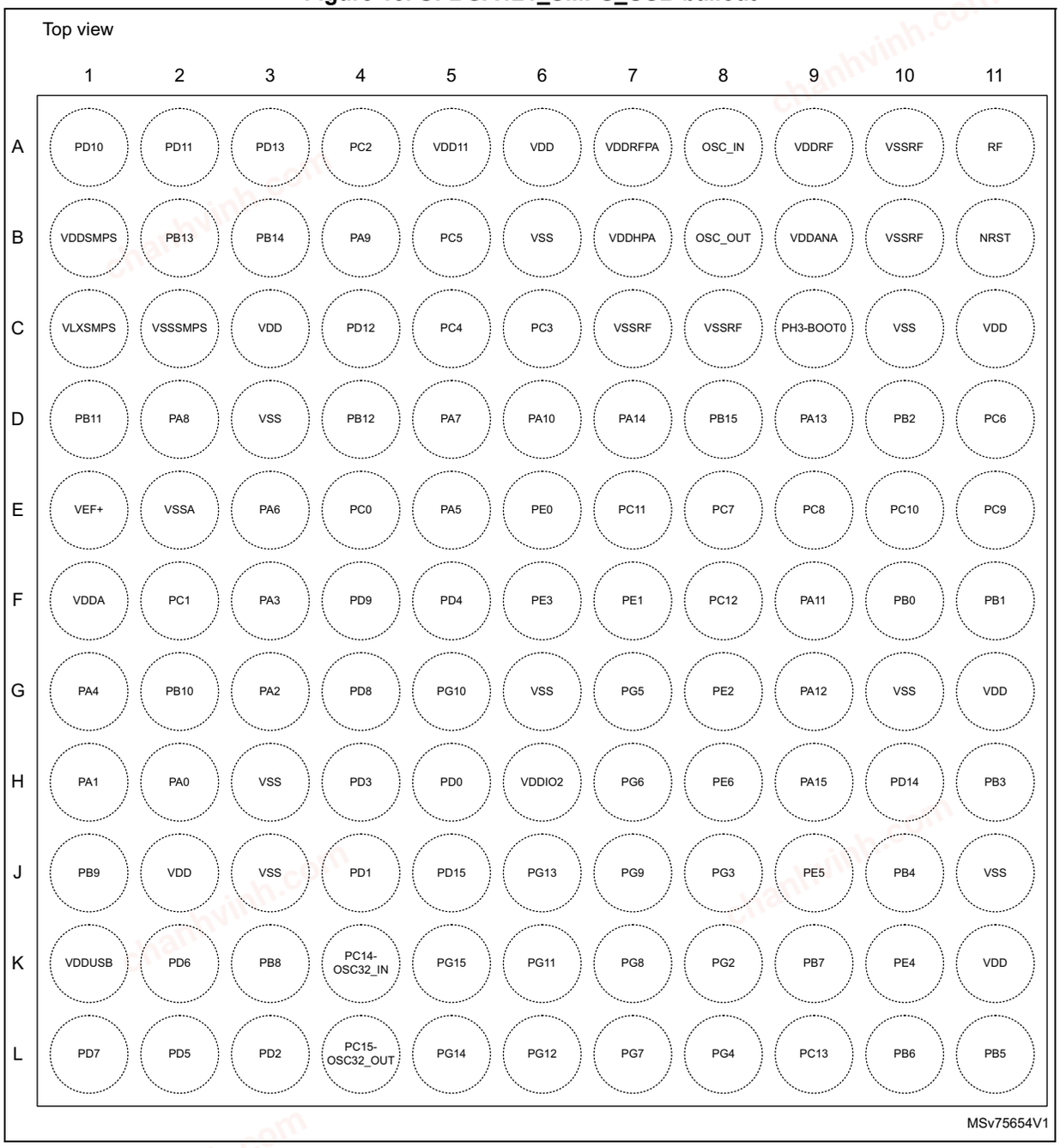
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Figure 14. UFBGA121_USB ballout



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Figure 15. UFBGA121_SMPS_USB ballout



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Table 22. Legend/abbreviations used in the pinout table

Name		Abbreviation	Definition
Pin name		Unless otherwise specified in brackets below the pin name, the pin function during and after reset is the same as the actual pin name	
Pin type		S	Supply pin
		I	Input only pin
		I/O	Input / output pin
I/O structure		FT	5 V-tolerant I/O
		TT	3.6 V-tolerant I/O
		RF	RF I/O
		RST	Bidirectional reset pin with weak pull-up resistor
		Option for TT or FT I/Os(1)	
		_a	I/O with analog switch function supplied by V_{DDA}
		_f	I/O, Fm+ capable
		_h	I/O with high-speed low voltage mode
		_s	I/O, supplied only by V_{DDIO2}
		_u	I/O with USB function supplied by V_{DDUSB}
Notes		Unless otherwise specified by a note, all I/Os are set as analog inputs during and after reset.	
Pin functions	Alternate functions	Functions selected through GPIOx_AFR registers	
	Additional functions	Functions directly selected/enabled through peripheral registers	

1. The related I/O structures in *Table 23* are a concatenation of various options. Examples: FT_a, FT_fa, FT_f.

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Table 23. Device pin definitions

Pin number								Name (function after reset)	Pin type	I/O structure	Notes	Alternate functions	Additional functions
UFQFPN48 USB	UFQFPN48 SMPS	UFQFPN48 SMPS USB	VFQFPN68 SMPS USB	Thin WLCSP88 USB	Thin WLCSP88-SMPS USB	UFBGA121 USB	UFBGA121 SMPS USB						
-	-	-	-	A10	-	C2	-	VSS	S	-	-	-	-
-	1	1	1	-	A10	-	C2	VSSSMPS	S	-	-	-	-
-	-	-	-	B11	-	B1	-	VSS	S	-	-	-	-
-	2	2	2	-	B11	-	B1	VDDSMPS	S	-	-	-	-
-	-	-	-	D11	-	C1	-	VSS	S	-	-	-	-
-	3	3	3	-	D11	-	C1	VLXSMPS	S	-	-	-	-
1	4	4	4	E10	E10	D4	D4	PB12	I/O	FT	-	TIM2_CH1, TIM2_ETR, I2C2_SMBA, SPI1_RDY, SPI2_NSS, USART1_TX, USART3_CK, TSC_SYNC, SAI1_SD_A, TIM3_ETR, EVENTOUT	-
2	-	-	5	F9	F9	D1	D1	PB11	I/O	FT_f	-	LPTIM1_CH1, LPTIM1_ETR, I2C4_SDA, I2C2_SDA, SPI2_RDY, USART3_RX, LPUART1_TX, EVENTOUT	-
3	5	5	6	F11	F11	D2	D2	PA8	I/O	FT_a	-	MCO, TIM2_CH2, LPTIM1_CH2, SPI3_RDY, USART1_RX, TSC_G1_IO1, OTG_SOF, SAI1_FS_A, EVENTOUT	ADC4_IN1
4	6	6	7	G10	G10	D5	D5	PA7	I/O	FT_fa	-	TIM2_CH3, I2C3_SDA, SPI3_SCK, USART1_CTS, USART3_TX, TSC_G1_IO2, COMP1_OUT, SAI1_SCK_A, EVENTOUT	ADC4_IN2, WKUP8, TAMP_IN1/TAMP_OUT2
5	7	7	8	H9	H9	E3	E3	PA6	I/O	FT_fa	-	CSTOP, TIM2_CH4, SAI1_CK2, I2C3_SCL, SPI3_RDY, USART1_RTS_DE, USART3_CTS, TSC_G1_IO3, SAI1_MCLK_A, EVENTOUT	ADC4_IN3, WKUP7
-	-	-	-	J10	J10	E2	E2	VSSA	S	-	-	-	
-	-	-	9	H11	H11	E1	E1	VREF+	S	-	-	-	-
6	8	8	10	K11	K11	F1	F1	VDDA	S	-	-	-	-

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Table 23. Device pin definitions (continued)

Pin number								Name (function after reset)	Pin type	I/O structure	Notes	Alternate functions	Additional functions
UFQFPN48 USB	UFQFPN48 SMPS	UFQFPN48 SMPS USB	VFQFPN68 SMPS USB	Thin WLCSP88 USB	Thin WLCSP88-SMPS USB	UFBGA121 USB	UFBGA121 SMPS USB						
-	-	-	-	J8	J8	F2	F2	PC1	I/O	FT_f	-	LPTIM1_CH1, SPI2_MOSI, I2C3_SDA, LPUART1_TX, SAI1_SD_A, EVENTOUT	-
-	-	-	-	K9	K9	E4	E4	PC0	I/O	FT_f		LPTIM1_IN1, I2C3_SCL, SPI2_RDY, LPUART1_RX, LPTIM2_IN1, EVENTOUT	-
7	9	9	11	L8	L8	E5	E5	PA5	I/O	FT_a	-	CSLEEP, TIM2_CH1, TIM2_ETR, SAI1_D2, SPI3_NSS, USART1_CK, USART3_RX, TSC_G1_IO4, AUDIOCLK, LPTIM2_ETR, EVENTOUT	ADC4_IN4, WKUP6
-	-	-	12	M7	M7	G1	G1	PA4	I/O	FT_a	-	USART1_CTS, TSC_G4_IO1, AUDIOCLK, TIM16_CH1, EVENTOUT	ADC4_IN5, WKUP2, TAMP_IN6/TAMP_OUT3
8	-	-	13	L10	L10	F3	F3	PA3	I/O	FT_a	-	USART1_RTS_DE, TSC_G4_IO2, TIM16_CH1N, EVENTOUT	ADC4_IN6, WKUP5
9	-	-	14	M9	M9	G2	G2	PB10	I/O	FT_a	-	I2C4_SCL, I2C2_SCL, SPI2_SCK, USART1_CK, USART3_TX, TSC_G4_IO3, TIM16_BKIN, EVENTOUT	-
10	10	10	15	N8	N8	G3	G3	PA2	I/O	FT_a	-	TIM1_BKIN, TIM3_CH1, SAI1_D1, USART1_RTS_DE, LPUART1_TX, TSC_G4_IO4, TIM16_CH1, EVENTOUT	COMP1_INP1, ADC4_IN7, WKUP4, LSCO
-	-	-	-	P11	P11	H3	H3	VSS	S	-	-	-	-
11	11	11	16	M11	M11	J2	J2	VDD	S	-	-	-	-
12	12	12	17	N10	N10	H1	H1	PA1	I/O	FT_a	-	TIM1_CH1N, TIM3_CH2, SAI1_CK1, SPI1_RDY, SPI3_MISO, USART1_CK, LPUART1_RX, TSC_G2_IO1, LPTIM2_CH2, TIM17_CH1, EVENTOUT	COMP1_INM1, ADC4_IN8, WKUP3
-	13	-	18	P9	P9	H2	H2	PA0	I/O	FT_a	-	LPTIM1_IN1, TIM1_CH2N, TIM3_CH3, SPI3_SCK, LPUART1_CTS, TSC_G2_IO2, TIM3_ETR, EVENTOUT	COMP2_INP1, ADC4_IN9, WKUP1

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Table 23. Device pin definitions (continued)

Pin number								Name (function after reset)	Pin type	I/O structure	Notes	Alternate functions	Additional functions
UFQFPN48 USB	UFQFPN48 SMPS	UFQFPN48 SMPS USB	VFQFPN68 SMPS USB	Thin WLCSP88 USB	Thin WLCSP88-SMPS USB	UFBGA121 USB	UFBGA121 SMPS USB						
-	14	-	19	R10	R10	J1	J1	PB9	I/O	FT_a	-	TIM1_CH3N, TIM3_CH4, IR_OUT, SPI2_NSS, SPI3_MISO, LPUART1_RTS_DE, TSC_G2_IO3, TIM4_CH4, LPTIM2_IN1, TIM16_CH1, EVENTOUT	COMP2_INM1, ADC4_IN10, WKUP8
13	-	13	20	T11	T11	K1	K1	VDDUSB	S	-	-	-	-
14	-	14	21	P7	P7	F4	F4	PD9	I/O	FT_u	-	USART2_TX, USART3_TX, EVENTOUT	OTG_VBUS
15	-	15	22	R8	R8	G4	G4	PD8	I/O	FT_u	-	USART2_CK, OTG_ID, EVENTOUT	-
16	-	16	23	U10	U10	L1	L1	PD7	I/O	TT	-	-	OTG_HSDM
17	-	17	24	T9	T9	K2	K2	PD6	I/O	TT	-	-	OTG_HSDP
-	-	-	25	N6	N6	L2	L2	PD5	I/O	FT	-	SAI1_D1, SPI3_MOSI, USART2_RX, SAI1_SD_A, EVENTOUT	-
18	15	18	26	R6	R6	K3	K3	PB8	I/O	FT_a	-	LPTIM1_ETR, TIM1_CH1, TIM3_ETR, USART2_RX, SPI3_MOSI, TSC_G2_IO4, COMP1_OUT, TIM4_CH3, TIM16_CH1N, EVENTOUT	PVD_IN
-	-	-	-	-	-	F5	F5	PD4	I/O	FT	-	LPTIM2_IN2, USART3_RX, EVENTOUT	-
-	-	-	-	-	-	H4	H4	PD3	I/O	FT_a	-	SPI2_SCK, SPI2_MISO, USART2_CTS, TSC_G8_IO1, EVENTOUT	-
-	-	-	-	-	-	L3	L3	PD2	I/O	FT	-	TIM3_ETR, USART3_RTS_DE, TSC_SYNC, EVENTOUT	-
-	-	-	27	-	-	-	-	VDD	S	-	-	-	-
19	16	19	28	U8	U8	L4	L4	PC15-OSC32_OUT	I/O	FT	-	EVENTOUT	OSC32_OUT
20	17	20	29	T7	T7	K4	K4	PC14-OSC32_IN	I/O	FT	-	EVENTOUT	OSC32_IN
-	-	-	-	-	-	J4	J4	PD1	I/O	FT_a	-	SPI2_SCK, TSC_G8_IO2, EVENTOUT	-

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Table 23. Device pin definitions (continued)

Pin number								Name (function after reset)	Pin type	I/O structure	Notes	Alternate functions	Additional functions
UFQFPN48 USB	UFQFPN48 SMPS	UFQFPN48 SMPS USB	VFQFPN68 SMPS USB	Thin WLCSP88 USB	Thin WLCSP88-SMPS USB	UFBGA121 USB	UFBGA121 SMPS USB						
-	-	-	-	-	-	H5	H5	PD0	I/O	FT_a	-	SPI2_NSS, TSC_G8_IO3, EVENTOUT	-
-	-	-	-	-	-	J5	J5	PD15	I/O	FT_a	-	TSC_G8_IO4, TIM4_CH4, EVENTOUT	-
-	-	-	-	-	-	K5	K5	PG15	I/O	FT_hs	-	LPTIM1_CH1, I2C1_SMBA, EVENTOUT	-
-	-	-	-	-	-	L5	L5	PG14	I/O	FT_hfs	-	LPTIM1_CH2, I2C1_SCL, EVENTOUT	-
-	-	-	-	-	-	H6	H6	VDDIO2	S	-	-	-	-
-	-	-	-	K7	K7	G6	G6	VSS	S	-	-	-	-
-	-	-	-	-	-	J6	J6	PG13	I/O	FT_hfs	-	I2C1_SDA, SPI3_RDY, USART1_CK, EVENTOUT	-
-	-	-	-	-	-	L6	L6	PG12	I/O	FT_hs	-	LPTIM1_ETR, SPI3_NSS, USART1_RTS_DE, SAI1_SD_A, EVENTOUT	-
-	-	-	-	-	-	K6	K6	PG11	I/O	FT_hs	-	LPTIM1_IN2, SPI3_MOSI, USART1_CTS, SAI1_MCLK_A, EVENTOUT	-
-	-	-	-	-	-	G5	G5	PG10	I/O	FT_hs	-	LPTIM1_IN1, SPI3_MISO, USART1_RX, SAI1_FS_A, EVENTOUT	-
-	-	-	-	-	-	J7	J7	PG9	I/O	FT_hs	-	SPI3_SCK, USART1_TX, SAI1_SCK_A, EVENTOUT	-
-	-	-	-	-	-	K7	K7	PG8	I/O	FT_hfs	-	I2C3_SDA, LPUART1_RX, EVENTOUT	-
-	-	-	-	-	-	L7	L7	PG7	I/O	FT_hfs	-	SAI1_CK1, I2C3_SCL, LPUART1_TX, SAI1_MCLK_A, EVENTOUT	-
-	-	-	-	-	-	H7	H7	PG6	I/O	FT_hs	-	I2C3_SMBA, SPI1_RDY, LPUART1_RTS_DE, EVENTOUT	-
-	-	-	-	-	-	G7	G7	PG5	I/O	FT_hs	-	SPI1_NSS, LPUART1_CTS, SAI1_SD_B, EVENTOUT	-
-	-	-	-	-	-	L8	L8	PG4	I/O	FT_hs	-	SPI1_MOSI, SAI1_MCLK_B, EVENTOUT	-

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Table 23. Device pin definitions (continued)

Pin number								Name (function after reset)	Pin type	I/O structure	Notes	Alternate functions	Additional functions
UFQFPN48 USB	UFQFPN48 SMPS	UFQFPN48 SMPS USB	VFQFPN68 SMPS USB	Thin WLCSP88 USB	Thin WLCSP88-SMPS USB	UFBGA121 USB	UFBGA121 SMPS USB						
-	-	-	-	-	-	J8	J8	PG3	I/O	FT_hs	-	SPI1_MISO, SAI1_FS_B, EVENTOUT	-
-	-	-	-	-	-	K8	K8	PG2	I/O	FT_hs	-	SPI1_SCK, SAI1_SCK_B, EVENTOUT	-
-	-	-	-	L6	L6	J3	J3	VSS	S	-	-	-	-
21	18	21	30	U6	U6	L9	L9	PC13	I/O	FT_a	-	TIM1_BKIN2, TSC_G5_IO1, EVENTOUT	WKUP2, RTC_TS/ RTC_OUT1, TAMP_IN4/TAMP_OUT5
-	19	-	-	T5	T5	K9	K9	PB7	I/O	FT_a	-	TIM1_CH4N, TSC_G5_IO2, TIM4_CH2, SAI1_SD_B, EVENTOUT	WKUP5, TAMP_IN5/TAMP_OUT4
-	-	-	-	-	-	H8	H8	PE6	I/O	FT	-	TIM3_CH4, SAI1_D1, SAI1_SD_A, EVENTOUT	-
-	20	-	-	U4	U4	L10	L10	PB6	I/O	FT_a	-	TIM2_CH1, TIM2_ETR, TSC_G5_IO3, TIM4_CH1, SAI1_SCK_B, EVENTOUT	WKUP3
-	-	-	-	-	-	J9	J9	PE5	I/O	FT	-	TIM3_CH3, SAI1_CK2, SAI1_SCK_A, EVENTOUT	-
-	21	-	-	P5	P5	L11	L11	PB5	I/O	FT_a	-	TIM3_CH1, SAI1_D2, LPUART1_TX, TSC_G5_IO4, SAI1_FS_B, EVENTOUT	-
-	-	-	-	-	-	K10	K10	PE4	I/O	FT	-	TIM3_CH2, SAI1_D2, SAI1_FS_A, EVENTOUT	-
22	22	22	31	-	-	K11	K11	VDD	S	-	-	-	-
-	-	-	-	K5	K5	J11	J11	VSS	S	-	-	-	-
23	23	23	32	R4	R4	J10	J10	PB4(NJRST)	I/O	FT_a	(1)	NJTRST, TIM1_CH3, LPTIM2_IN2, USART2_RX, SPI1_SCK, TSC_G3_IO1, PTA_PRIORITY, PTA_ACTIVE, SAI1_MCLK_B, TIM17_CH1, EVENTOUT	-
-	-	-	33	U2	U2	F6	F6	PE3	I/O	FT_ha	-	TRACED2, TIM3_CH1, TSC_G7_IO1, SAI1_SD_B, EVENTOUT	-

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Table 23. Device pin definitions (continued)

Pin number								Name (function after reset)	Pin type	I/O structure	Notes	Alternate functions	Additional functions
UFQFPN48 USB	UFQFPN48 SMPS	UFQFPN48 SMPS USB	VFQFPN68 SMPS USB	Thin WLCSP88 USB	Thin WLCSP88-SMPS USB	UFBGA121 USB	UFBGA121 SMPS USB						
-	-	-	34	T3	T3	G8	G8	PE2	I/O	FT_ha	-	TRACED1, TIM3_ETR, SAI1_CK1, TSC_G7_IO2, SAI1_MCLK_A, EVENTOUT	-
-	-	-	35	R2	R2	F7	F7	PE1	I/O	FT_ha	-	TRACED0, TSC_G7_IO3, TIM17_CH1, EVENTOUT	-
-	-	-	36	P3	P3	E6	E6	PE0	I/O	FT_ha	-	TRACECLK, TSC_G7_IO4, TIM4_ETR, TIM16_CH1, EVENTOUT	-
-	-	-	37	N4	N4	H10	H10	PD14	I/O	FT_h	-	TRACED3, TIM4_CH3, EVENTOUT	-
-	-	-	-	P1	P1	G10	G10	VSS	S	-	-	-	-
-	-	-	38	T1	T1	G11	G11	VDD	S	-	-	-	-
24	24	24	39	M5	M5	H11	H11	PB3 (JTDO/TRACESWO)	I/O	FT_fa	-	JTDO/TRACESWO, TIM1_CH4, LPTIM1_IN2, USART2_CK, I2C1_SDA, SPI1_MISO, TSC_G3_IO2, PTA_ACTIVE, TIM17_CH1N, EVENTOUT	-
25	25	25	40	N2	N2	H9	H9	PA15 (JTDI)	I/O	FT_fa	(1)	JTDI, TIM1_ETR, LPTIM1_CH2, USART2_RTS_DE, I2C1_SCL, SPI1_MOSI, USART3_RTS_DE, TSC_G3_IO3, PTA_STATUS, TIM17_BKIN, EVENTOUT	-
26	26	26	41	M3	M3	D7	D7	PA14 (JTCK/SWCLK)	I/O	FT	(1)	JTCK/SWCLK, USART2_TX, I2C4_SMBA, OTG_SOF/PTA_STATUS, COMP2_OUT, EVENTOUT	TAMP_IN3/TAMP_OUT6
27	27	27	42	L4	L4	D9	D9	PA13 (JTMS/SWDIO)	I/O	FT	(1)	JTMS/SWDIO, IR_OUT, PTA_PRIORITY, EVENTOUT	-
28	28	28	43	K3	K3	G9	G9	PA12	I/O	FT_a	-	TIM1_CH2, USART2_TX, SPI1_NSS, TSC_G3_IO4, PTA_STATUS, RF_ANTSW0, COMP2_OUT, EVENTOUT	WKUP6
29	29	29	44	L2	L2	F9	F9	PA11.	I/O	FT	-	TIM1_CH1, USART2_RX, RF_ANTSW1, LPTIM2_CH1, EVENTOUT	-

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Table 23. Device pin definitions (continued)

Pin number								Name (function after reset)	Pin type	I/O structure	Notes	Alternate functions	Additional functions
UFQFPN48 USB	UFQFPN48 SMPS	UFQFPN48 SMPS USB	VFQFPN68 SMPS USB	Thin WLCSP88 USB	Thin WLCSP88-SMPS USB	UFBGA121 USB	UFBGA121 SMPS USB						
-	-	-	-	M1	M1	C11	C11	VDD	S	-	-	-	-
-	-	-	-	K1	K1	-	-	VSS	S	-	-	-	-
30	30	30	45	J4	J4	D10	D10	PB2	I/O	FT_f	-	TIM1_CH1N, USART2_CTS, I2C1_SCL, I2C3_SCL, RF_ANTSW2, EVENTOUT	WKUP1, RTC_OUT2
31	31	31	46	J2	J2	F11	F11	PB1	I/O	FT_f	-	TIM1_CH2N, USART2_RTS_DE, I2C1_SDA, I2C3_SDA, USART3_RTS_DE, EVENTOUT	WKUP4
32	32	32	47	H3	H3	F10	F10	PB0	I/O	FT	-	-TIM1_CH3N, LPTIM2_IN2, USART2_TX, SPI2_MOSI, USART3_CK, EVENTOUT	-
-	-	-	-	-	-	F8	F8	PC12	I/O	FT	-	SPI3_MOSI, USART3_CK, EVENTOUT	-
-	-	-	-	-	-	E7	E7	PC11	I/O	FT	-	SPI3_MISO, USART3_RX, EVENTOUT	-
-	-	-	-	-	-	E10	E10	PC10	I/O	FT	-	SPI3_SCK, USART3_TX, EVENTOUT	-
-	-	-	-	-	-	E11	E11	PC9	I/O	FT	-	TIM3_CH4, USART2_TX, EVENTOUT	-
-	-	-	-	G4	G4	E9	E9	PC8	I/O	FT	-	TIM3_CH3, USART2_RX, EVENTOUT	-
-	-	-	-	H1	H1	E8	E8	PC7	I/O	FT	-	CSTOP, TIM3_CH2, USART2_RTS_DE, LPTIM2_CH2, EVENTOUT	-
-	-	-	-	J6	J6	-	-	VSS	S	-	-	-	-
-	-	-	-	F5	F5	D11	D11	PC6	I/O	FT	-	CSLEEP, TIM3_CH1, EVENTOUT	-
33	33	33	48	G2	G2	D8	D8	PB15	I/O	TT	-	TIM1_BKIN2, USART2_CTS, I2C1_SMBA, I2C3_SMBA, LPUART1_CTS, PTA_GRANT, RF_EXTPABYP, TIM16_BKIN, EVENTOUT	-
34	34	34	49	C6	C6	C9	C9	PH3-BOOT0	I/O	TT	-	PTA_GRANT, RF_EXTPABYP, EVENTOUT	TAMP_IN2/TAMP_OUT1
35	35	35	50	-	-	-	-	VDD	S	-	-	-	-
-	-	-	-	H5	H5	C10	C10	VSS	S	-	-	-	-

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Table 23. Device pin definitions (continued)

Pin number								Name (function after reset)	Pin type	I/O structure	Notes	Alternate functions	Additional functions
UFQFPN48 USB	UFQFPN48 SMPS	UFQFPN48 SMPS USB	VFQFPN68 SMPS USB	Thin WLCSP88 USB	Thin WLCSP88-SMPS USB	UFBGA121 USB	UFBGA121 SMPS USB						
36	36	36	51	E6	E6	B11	B11	NRST	I/O	RST	-	-	-
-	-	-	-	G6	G6	-	-	VSS	S	-	-	-	-
-	-	-	-	F1	F1	B10	B10	VSSRF	S	-	-	-	-
37	37	37	52	D1	D1	A11	A11	RF	I/O	RF	-	-	-
-	-	-	-	E2	E2	A10	A10	VSSRF	S	-	-	-	-
38	38	38	53	E4	E4	B7	B7	VDDHPA	S	-	-	-	-
-	39	39	54	-	C4	-	B9	VDDANA	S	-	-	-	-
-	-	-	-	C4	-	B9	-	VDDRF	S	-	-	-	-
39	40	40	55	A4	A4	A9	A9	VDDRF	S	-	-	-	-
-	-	-	-	F3	F3	C7	C7	VSSRF	S	-	-	-	-
40	41	41	56	D5	D5	B8	B8	OSC_OUT	O	RF	-	-	-
41	42	42	57	B5	B5	A8	A8	OSC_IN	I	RF	-	-	-
42	43	43	58	A6	A6	A7	A7	VDDRFPA	S	-	-	-	-
43	44	44	59	B7	B7	A6	A6	VDD	S	-	-	-	-
-	-	-	-	C8	C8	B6	B6	VSS	S	-	-	-	-
-	45	45	60	-	A8	-	A5	VDD11	S	-	-	-	-
44	-	-	-	A8	-	A5	-	VCAP	S	-	-	-	-
-	-	-	61	F7	F7	B5	B5	PC5	I/O	FT	-	TIM1_CH4N, SAI1_D3, USART3_RX, SAI1_SD_B, EVENTOUT	-
-	-	-	62	G8	G8	C5	C5	PC4	I/O	FT	-	TIM3_CH2, SAI1_D2, SPI3_MISO, USART3_TX, SAI1_FS_A, LPTIM2_CH2, EVENTOUT	-

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Table 23. Device pin definitions (continued)

Pin number								Name (function after reset)	Pin type	I/O structure	Notes	Alternate functions	Additional functions
UFQFPN48 USB	UFQFPN48 SMPS	UFQFPN48 SMPS USB	VFQFPN68 SMPS USB	Thin WLCSP88 USB	Thin WLCSP88-SMPS USB	UFBGA121 USB	UFBGA121 SMPS USB						
-	-	-	63	E8	E8	C6	C6	PC3	I/O	FT	-	LPTIM1_ETR, TIM3_CH1, SAI1_D1, SPI2_MOSI, SPI3_MOSI, SAI1_SD_A, LPTIM2_ETR, EVENTOUT	-
45	46	46	64	D7	D7	D6	D6	PA10	I/O	FT	-	TIM3_CH1, SAI1_D1, SPI2_NSS, LPUART1_RX, EVENTOUT	-
-	-	-	-	-	-	A4	A4	PC2	I/O	FT	-	LPTIM1_IN2, SPI2_MISO, EVENTOUT	-
46	47	47	65	B9	B9	B4	B4	PA9	I/O	FT	-	TIM3_CH2, SAI1_CK1, SPI2_MISO, SPI2_SCK, LPUART1_RTS_DE, EVENTOUT	-
-	-	-	-	-	-	A13	A13	PD13	I/O	FT_fa	-	I2C4_SDA, TSC_G6_IO4, TIM4_CH2, LPTIM2_CH1, EVENTOUT	-
-	-	-	-	-	-	C4	C4	PD12	I/O	FT_fa	-	I2C4_SCL, USART3_RTS_DE, TSC_G6_IO3, TIM4_CH1, LPTIM2_IN1, EVENTOUT	-
47	48	48	66	D9	D9	B3	B3	PB14	I/O	FT_a	-	RTC_REFIN, TIM3_CH3, I2C2_SDA, SPI2_MISO, USART1_TX, USART3_RTS_DE, TSC_G6_IO1, SAI1_SD_A, EVENTOUT	WKUP7
-	-	-	-	-	-	A2	A2	PD11	I/O	FT	-	I2C4_SMBA, USART3_CTS, LPTIM2_ETR, EVENTOUT	-
-	-	-	-	-	-	A1	A1	PD10	I/O	FT	-	LPTIM2_CH2, USART3_CK, EVENTOUT	-
48	-	-	67	C10	C10	B2	B2	PB13	I/O	FT_a	-	TIM3_CH4, I2C2_SCL, SPI2_SCK, USART3_CTS, TSC_G6_IO2, EVENTOUT	-
-	-	-	-	H7	H7	D3	D3	VSS	S	-	-	-	-
-	-	-	68	-	-	C3	C3	VDD	S	-	-	-	-
49	49	49	69	-	-	-	-	VSS (exposed pad)	S	-	-	-	-

1. After reset, this pin is configured as JTAG/SWD alternate functions. The internal pull-up on PA15, PA13, and PB4 pins, and the internal pull-down on PA14 pin are activated.

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4.2 Alternate functions

Table 24. Alternate functions (AF0 to AF7)[1]

Port		AF0	AF1	AF2	AF3	AF4	AF5	AF6	AF7
		LPTIM1/SYS	LPTIM1/ TIM1/2	LPTIM1/2/ TIM1/2/3	I2C4/SAI1/SPI2 /USART2	I2C1/2/3/4/ OTG	I2C4/ SPI1/2/3	I2C3/ SPI2/3	USART1/2/3
Port A	PA0	LPTIM1_IN1	TIM1_CH2N	TIM3_CH3	-	-	-	SPI3_SCK	-
	PA1	-	TIM1_CH1N	TIM3_CH2	SAI1_CK1	-	SPI1_RDY	SPI3_MISO	USART1_CK
	PA2	-	TIM1_BKIN	TIM3_CH1	SAI1_D1	-	-	-	USART1_RTS_DE
	PA3	-	-	-	-	-	-	-	USART1_RTS_DE
	PA4	-	-	-	-	-	-	-	USART1_CTS
	PA5	CSLEEP	TIM2_CH1	TIM2_ETR	SAI1_D2	-	-	SPI3_NSS	USART1_CK
	PA6	CSTOP	TIM2_CH4	-	SAI1_CK2	I2C3_SCL	-	SPI3_RDY	USART1_RTS_DE
	PA7	-	TIM2_CH3	-	-	I2C3_SDA	-	SPI3_SCK	USART1_CTS
	PA8	MCO	TIM2_CH2	LPTIM1_CH2	-	-	-	SPI3_RDY	USART1_RX
	PA9	-	-	TIM3_CH2	SAI1_CK1	-	SPI2_MISO	SPI2_SCK	-
	PA10	-	-	TIM3_CH1	SAI1_D1	-	-	SPI2_NSS	-
	PA11	-	TIM1_CH1	-	USART2_RX	-	-	-	-
	PA12	-	TIM1_CH2	-	USART2_TX	-	SPI1_NSS	-	-
	PA13	JTMS/SWDIO	IR_OUT	-	-	-	-	-	-
	PA14	JTCK/SWCLK	-	-	USART2_TX	OTG_SOF	I2C4_SMBA	-	-
	PA15	JTDI	TIM1_ETR	LPTIM1_CH2	USART2_RTS_DE	I2C1_SCL	SPI1_MOSI	-	USART3_RTS_DE

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Table 24. Alternate functions (AF0 to AF7)(1) (continued)

Port		AF0	AF1	AF2	AF3	AF4	AF5	AF6	AF7
		LPTIM1/SYS	LPTIM1/ TIM1/2	LPTIM1/2/ TIM1/2/3	I2C4/SAI1/SPI2 /USART2	I2C1/2/3/4/ OTG	I2C4/ SPI1/2/3	I2C3/ SPI2/3	USART1/2/3
Port B	PB0	-	TIM1_CH3N	LPTIM2_IN2	USART2_TX	-	SPI2_MOSI	-	USART3_CK
	PB1	-	TIM1_CH2N	-	USART2_RTS_DE	I2C1_SDA	-	I2C3_SDA	USART3_RTS_DE
	PB2	-	TIM1_CH1N	-	USART2_CTS	I2C1_SCL	-	I2C3_SCL	-
	PB3	JTDO/ TRACESWO	TIM1_CH4	LPTIM1_IN2	USART2_CK	I2C1_SDA	SPI1_MISO	-	-
	PB4	NJTRST	TIM1_CH3	LPTIM2_IN2	USART2_RX	-	SPI1_SCK	-	-
	PB5	-	-	TIM3_CH1	SAI1_D2	-	-	-	-
	PB6	-	TIM2_CH1	TIM2_ETR	-	-	-	-	-
	PB7	-	TIM1_CH4N	-	-	-	-		-
	PB8	LPTIM1_ETR	TIM1_CH1	TIM3_ETR	USART2_RX	-	-	SPI3_MOSI	-
	PB9	-	TIM1_CH3N	TIM3_CH4	IR_OUT	-	SPI2_NSS	SPI3_MISO	-
	PB10	-	-	-	I2C4_SCL	I2C2_SCL	SPI2_SCK	-	USART1_CK
	PB11	LPTIM1_CH1	-	LPTIM1_ETR	I2C4_SDA	I2C2_SDA	SPI2_RDY	-	USART3_RX
	PB12	-	TIM2_CH1	TIM2_ETR	-	I2C2_SMBA	SPI1_RDY	SPI2_NSS	USART1_TX
	PB13	-	-	TIM3_CH4	-	I2C2_SCL	SPI2_SCK	-	USART3_CTS
	PB14	RTC_REFIN	-	TIM3_CH3	-	I2C2_SDA	SPI2_MISO	-	USART1_TX
	PB15	-	TIM1_BKIN2	-	USART2_CTS	I2C1_SMBA	-	I2C3_SMBA	-

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Table 24. Alternate functions (AF0 to AF7)[1] (continued)

Port		AF0	AF1	AF2	AF3	AF4	AF5	AF6	AF7
		LPTIM1/SYS	LPTIM1/ TIM1/2	LPTIM1/2/ TIM1/2/3	I2C4/SAI1/SPI2 /USART2	I2C1/2/3/4/ OTG	I2C4/ SPI1/2/3	I2C3/ SPI2/3	USART1/2/3
Port C	PC0	-	LPTIM1_IN1	-	-	I2C3_SCL	SPI2_RDY	-	-
	PC1	-	LPTIM1_CH1	-	SPI2_MOSI	I2C3_SDA	-	-	-
	PC2	-	LPTIM1_IN2	-	-	-	SPI2_MISO	-	-
	PC3	-	LPTIM1_ETR	TIM3_CH1	SAI1_D1	-	SPI2_MOSI	SPI3_MOSI	-
	PC4	-	-	TIM3_CH2	SAI1_D2	-	-	SPI3_MISO	USART3_TX
	PC5	-	TIM1_CH4N	-	SAI1_D3	-	-	-	USART3_RX
	PC6	CSLEEP	-	TIM3_CH1	-	-	-	-	-
	PC7	CSTOP	-	TIM3_CH2	-	-	-	-	USART2_RTS_DE
	PC8	-	-	TIM3_CH3	-	-	-	-	USART2_RX
	PC9	-	-	TIM3_CH4	-	-	-	-	USART2_TX
	PC10	-	-	-	-	-	-	SPI3_SCK	USART3_TX
	PC11	-	-	-	-	-	-	SPI3_MISO	USART3_RX
	PC12	-	-	-	-	-	-	SPI3_MOSI	USART3_CK
	PC13	-	-	TIM1_BKIN2	-	-	-	-	-
	PC14	-	-	-	-	-	-	-	-
	PC15	-	-	-	-	-	-	-	-

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Table 24. Alternate functions (AF0 to AF7)(1) (continued)

Port		AF0	AF1	AF2	AF3	AF4	AF5	AF6	AF7
		LPTIM1/SYS	LPTIM1/ TIM1/2	LPTIM1/2/ TIM1/2/3	I2C4/SAI1/SPI2 /USART2	I2C1/2/3/4/ OTG	I2C4/ SPI1/2/3	I2C3/ SPI2/3	USART1/2/3
Port D	PD0	-	-	-	-	-	SPI2_NSS	-	-
	PD1	-	-	-	-	-	SPI2_SCK	-	-
	PD2	-	-	TIM3_ETR	-	-	-	-	USART3_RTS_DE
	PD3	-	-	-	SPI2_SCK	-	SPI2_MISO	-	USART2_CTS
	PD4	-	-	LPTIM2_IN2	-	-	-	-	USART3_RX
	PD5	-	-	-	SAI1_D1	-	SPI3_MOSI	-	USART2_RX
	PD6	-	-	-	-	-	-	-	-
	PD7	-	-	-	-	-	-	-	-
	PD8	-	-	-	-	-	-	-	USART2_CK
	PD9	-	-	-	USART2_TX	-	-	-	USART3_TX
	PD10	-	-	LPTIM2_CH2	-	-	-	-	USART3_CK
	PD11	-	-	-	-	I2C4_SMBA	-	-	USART3_CTS
	PD12	-	-	-	-	I2C4_SCL	-	-	USART3_RTS_DE
	PD13	-	-	-	-	I2C4_SDA	-	-	-
	PD14	TRACED3	-	-	-	-	-	-	-
	PD15	-	-	-	-	-	-	-	-
Port E	PE0	TRACECLK	-	-	-	-	-	-	-
	PE1	TRACED0	-	-	-	-	-	-	-
	PE2	TRACED1	-	TIM3_ETR	SAI1_CK1	-	-	-	-
	PE3	TRACED2	-	TIM3_CH1	-	-	-	-	-
	PE4	-	-	TIM3_CH2	SAI1_D2	-	-	-	-
	PE5	-	-	TIM3_CH3	SAI1_CK2	-	-	-	-
	PE6	-	-	TIM3_CH4	SAI1_D1	-	-	-	-

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Table 24. Alternate functions (AF0 to AF7)[1] (continued)

Port		AF0	AF1	AF2	AF3	AF4	AF5	AF6	AF7
		LPTIM1/SYS	LPTIM1/ TIM1/2	LPTIM1/2/ TIM1/2/3	I2C4/SAI1/SPI2 /USART2	I2C1/2/3/4/ OTG	I2C4/ SPI1/2/3	I2C3/ SPI2/3	USART1/2/3
Port G	PG2	-	-	-	-	-	SPI1_SCK	-	-
	PG3	-	-	-	-	-	SPI1_MISO	-	-
	PG4	-	-	-	-	-	SPI1_MOSI	-	-
	PG5	-	-	-	-	-	SPI1_NSS	-	-
	PG6	-	-	-	-	I2C3_SMBA	SPI1_RDY	-	-
	PG7	-	-	-	SAI1_CK1	I2C3_SCL	-	-	-
	PG8	-	-	-	-	I2C3_SDA	-	-	-
	PG9	-	-	-	-	-	-	SPI3_SCK	USART1_TX
	PG10	-	LPTIM1_IN1	-	-	-	-	SPI3_MISO	USART1_RX
	PG11	-	LPTIM1_IN2	-	-	-	-	SPI3_MOSI	USART1_CTS
	PG12	-	LPTIM1_ETR	-	-	-	-	SPI3_NSS	USART1_RTS_DE
	PG13	-	-	-	-	I2C1_SDA	-	SPI3_RDY	USART1_CK
	PG14	-	LPTIM1_CH2	-	-	I2C1_SCL	-	-	-
	PG15	-	LPTIM1_CH1	-	-	I2C1_SMBA	-	-	-
Port H	PH3	-	-	-	-	-	-	-	-

1. For AF8 to AF15 refer to *Table 25*.

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Table 25. Alternate functions (AF8 to AF15)[1]

Port		AF8	AF9	AF10	AF11	AF12	AF13	AF14	AF15
		LPUART1 /USART3	TSC	OTG/PTA	RF	COMP1/2 /PTA/TIM4	LPTIM2/SAI1 /TIM4	LPTIM2/ TIM3/16/17	EVENTOUT
Port A	PA0	LPUART1_CTS	TSC_G2_IO2	-	-	-	-	TIM3_ETR	EVENTOUT
	PA1	LPUART1_RX	TSC_G2_IO1	-	-	-	LPTIM2_CH2	TIM17_CH1	EVENTOUT
	PA2	LPUART1_TX	TSC_G4_IO4	-	-	-	-	TIM16_CH1	EVENTOUT
	PA3	-	TSC_G4_IO2	-	-	-	-	TIM16_CH1N	EVENTOUT
	PA4	-	TSC_G4_IO1	-	-	-	AUDIOCLK	TIM16_CH1	EVENTOUT
	PA5	USART3_RX	TSC_G1_IO4	-	-	-	AUDIOCLK	LPTIM2_ETR	EVENTOUT
	PA6	USART3_CTS	TSC_G1_IO3	-	-	-	SAI1_MCLK_A	-	EVENTOUT
	PA7	USART3_TX	TSC_G1_IO2	-	-	COMP1_OUT	SAI1_SCK_A	-	EVENTOUT
	PA8	-	TSC_G1_IO1	OTG_SOF	-	-	SAI1_FS_A	-	EVENTOUT
	PA9	LPUART1_RTS_DE	-	-	-	-	-	-	EVENTOUT
	PA10	LPUART1_RX	-	-	-	-	-	-	EVENTOUT
	PA11	-	-	-	RF_ANTSW1	-	-	LPTIM2_CH1	EVENTOUT
	PA12	-	TSC_G3_IO4	PTA_STATUS	RF_ANTSW0	COMP2_OUT	-	-	EVENTOUT
	PA13	-	-	PTA_PRIORITY	-	-	-	-	EVENTOUT
	PA14	-	-	PTA_STATUS	-	COMP2_OUT	-	-	EVENTOUT
	PA15	-	TSC_G3_IO3	PTA_STATUS	-	-	-	TIM17_BKIN	EVENTOUT

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Table 25. Alternate functions (AF8 to AF15)[1] (continued)

Port		AF8	AF9	AF10	AF11	AF12	AF13	AF14	AF15
		LPUART1 /USART3	TSC	OTG/PTA	RF	COMP1/2 /PTA/TIM4	LPTIM2/SAI1 /TIM4	LPTIM2/ TIM3/16/17	EVENTOUT
Port B	PB0	-	-	-	-	-	-	-	EVENTOUT
	PB1	-	-	-	-	-	-	-	EVENTOUT
	PB2	-	-	-	RF_ANTSW2	-	-	-	EVENTOUT
	PB3	-	TSC_G3_IO2	PTA_ACTIVE	-	-	-	TIM17_CH1N	EVENTOUT
	PB4	-	TSC_G3_IO1	PTA_PRIORITY	-	PTA_ACTIVE	SAI1_MCLK_B	TIM17_CH1	EVENTOUT
	PB5	LPUART1_TX	TSC_G5_IO4	-	-	-	SAI1_FS_B	-	EVENTOUT
	PB6	-	TSC_G5_IO3	-	-	TIM4_CH1	SAI1_SCK_B	-	EVENTOUT
	PB7	-	TSC_G5_IO2	-	-	TIM4_CH2	SAI1_SD_B	-	EVENTOUT
	PB8	-	TSC_G2_IO4	-	-	COMP1_OUT	TIM4_CH3	TIM16_CH1N	EVENTOUT
	PB9	LPUART1_RTS_DE	TSC_G2_IO3	-	-	TIM4_CH4	LPTIM2_IN1	TIM16_CH1	EVENTOUT
	PB10	USART3_TX	TSC_G4_IO3	-	-	-	-	TIM16_BKIN	EVENTOUT
	PB11	LPUART1_TX	-	-	-	-	-	-	EVENTOUT
	PB12	USART3_CK	TSC_SYNC	-	-	-	SAI1_SD_A	TIM3_ETR	EVENTOUT
	PB13	-	TSC_G6_IO2	-	-	-	-	-	EVENTOUT
	PB14	USART3_RTS_DE	TSC_G6_IO1	-	-	-	SAI1_SD_A	-	EVENTOUT
	PB15	LPUART1_CTS	-	PTA_GRANT	RF_EXTPABYP	-	-	TIM16_BKIN	EVENTOUT

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Table 25. Alternate functions (AF8 to AF15)[1] (continued)

Port		AF8	AF9	AF10	AF11	AF12	AF13	AF14	AF15
		LPUART1 /USART3	TSC	OTG/PTA	RF	COMP1/2 /PTA/TIM4	LPTIM2/SAI1 /TIM4	LPTIM2/ TIM3/16/17	EVENTOUT
Port C	PC0	LPUART1_RX	-	-	-	-	-	LPTIM2_IN1	EVENTOUT
	PC1	LPUART1_TX	-	-	-	-	SAI1_SD_A	-	EVENTOUT
	PC2	-	-	-	-	-	-	-	EVENTOUT
	PC3	-	-	-	-	-	SAI1_SD_A	LPTIM2_ETR	EVENTOUT
	PC4	-	-	-	-	-	SAI1_FS_A	LPTIM2_CH2	EVENTOUT
	PC5	-	-	-	-	-	SAI1_SD_B	-	EVENTOUT
	PC6	-	-	-	-	-	-	-	EVENTOUT
	PC7	-	-	-	-	-	-	LPTIM2_CH2	EVENTOUT
	PC8	-	-	-	-	-	-	-	EVENTOUT
	PC9	-	-	-	-	-	-	-	EVENTOUT
	PC10	-	-	-	-	-	-	-	EVENTOUT
	PC11	-	-	-	-	-	-	-	EVENTOUT
	PC12	-	-	-	-	-	-	-	EVENTOUT
	PC13	-	TSC_G5_IO1	-	-	-	-	-	EVENTOUT
	PC14	-	-	-	-	-	-	-	EVENTOUT
	PC15	-	-	-	-	-	-	-	EVENTOUT

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Table 25. Alternate functions (AF8 to AF15)(1) (continued)

Port		AF8	AF9	AF10	AF11	AF12	AF13	AF14	AF15
		LPUART1 /USART3	TSC	OTG/PTA	RF	COMP1/2 /PTA/TIM4	LPTIM2/SAI1 /TIM4	LPTIM2/ TIM3/16/17	EVENTOUT
Port D	PD0	-	TSC_G8_IO3	-	-	-	-	-	EVENTOUT
	PD1	-	TSC_G8_IO2	-	-	-	-	-	EVENTOUT
	PD2	-	TSC_SYNC	-	-	-	-	-	EVENTOUT
	PD3	-	TSC_G8_IO1	-	-	-	-	-	EVENTOUT
	PD4	-	-	-	-	-	-	-	EVENTOUT
	PD5	-	-	-	-	-	SAI1_SD_A	-	EVENTOUT
	PD6	-	-	-	-	-	-	-	-
	PD7	-	-	-	-	-	-	-	-
	PD8	-	-	OTG_ID	-	-	-	-	EVENTOUT
	PD9	-	-	-	-	-	-	-	EVENTOUT
	PD10	-	-	-	-	-	-	-	EVENTOUT
	PD11	-		-	-	-	-	LPTIM2_ETR	EVENTOUT
	PD12	-	TSC_G6_IO3	-	-	-	TIM4_CH1	LPTIM2_IN1	EVENTOUT
	PD13	-	TSC_G6_IO4	-	-	-	TIM4_CH2	LPTIM2_CH1	EVENTOUT
	PD14	-	-	-	-	-	TIM4_CH3	-	EVENTOUT
	PD15	-	TSC_G8_IO4	-	-	-	TIM4_CH4	-	EVENTOUT
Port E	PE0	-	TSC_G7_IO4	-	-	-	TIM4_ETR	TIM16_CH1	EVENTOUT
	PE1	-	TSC_G7_IO3	-	-	-	-	TIM17_CH1	EVENTOUT
	PE2	-	TSC_G7_IO2	-	-	-	SAI1_MCLK_A	-	EVENTOUT
	PE3	-	TSC_G7_IO1	-	-	-	SAI1_SD_B	-	EVENTOUT
	PE4	-	-	-	-	-	SAI1_FS_A	-	EVENTOUT
	PE5	-	-	-	-	-	SAI1_SCK_A	-	EVENTOUT
	PE6	-	-	-	-	-	SAI1_SD_A	-	EVENTOUT

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Table 25. Alternate functions (AF8 to AF15)(1) (continued)

Port		AF8	AF9	AF10	AF11	AF12	AF13	AF14	AF15
		LPUART1 /USART3	TSC	OTG/PTA	RF	COMP1/2 /PTA/TIM4	LPTIM2/SAI1 /TIM4	LPTIM2/ TIM3/16/17	EVENTOUT
Port G	PG2	-	-	-	-	-	SAI1_SCK_B	-	EVENTOUT
	PG3	-	-	-	-	-	SAI1_FS_B	-	EVENTOUT
	PG4	-	-	-	-	-	SAI1_MCLK_B	-	EVENTOUT
	PG5	LPUART1_CTS	-	-	-	-	SAI1_SD_B	-	EVENTOUT
	PG6	LPUSRT1_RTS_DE	-	-	-	-	-	-	EVENTOUT
	PG7	LPUART1_TX	-	-	-	-	SAI1_MCLK_A	-	EVENTOUT
	PG8	LPUART1_RX	-	-	-	-	-	-	EVENTOUT
	PG9	-	-	-	-	-	SAI1_SCK_A	-	EVENTOUT
	PG10	-	-	-	-	-	SAI1_FS_A	-	EVENTOUT
	PG11	-	-	-	-	-	SAI1_MCLK_A	-	EVENTOUT
	PG12	-	-	-	-	-	SAI1_SD_A	-	EVENTOUT
	PG13	-	-	-	-	-	-	-	EVENTOUT
	PG14	-	-	-	-	-	-	-	EVENTOUT
	PG15	-	-	-	-	-	-	-	EVENTOUT
Port H	PH3	-	-	PTA_GRANT	RF_EXTPABYP	-	-	-	EVENTOUT

1. For AF0 to AF7 refer to *Table 24*.

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5 Electrical characteristics

5.1 Parameter conditions

Unless otherwise specified, all voltages are referenced to V_{SS}.

5.1.1 Minimum and maximum values

Unless otherwise specified, the minimum and maximum values are guaranteed in the worst conditions of ambient temperature, supply voltage and frequencies by tests in production on 100% of the devices with an ambient temperature at T_A = 25 °C and T_A = T_A max (given by the selected temperature range).

Data based on characterization results, design simulation and/or technology characteristics are indicated in the table footnotes and are not tested in production. Based on characterization, the minimum and maximum values refer to sample tests and represent the mean value plus or minus three times the standard deviation (mean ± 3σ).

5.1.2 Typical values

Unless otherwise specified, typical data are based on T_A = 25 °C and supply voltage V_{DD} = V_{DDA} = V_{DDRF} = 3 V. They are only given as design guidelines and are not tested.

Typical ADC accuracy values are determined by characterization of a batch of samples from a standard diffusion lot over the full temperature range, where 95% of the devices have an error lower than or equal to the value indicated (mean ± 2σ).

5.1.3 Typical curves

Unless otherwise specified, all typical curves are given only as design guidelines, and are not tested.

5.1.4 Loading capacitor

Unless otherwise specified, the loading conditions used for pin parameter measurement are shown in *Figure 16*.

5.1.5 Pin input voltage

The input voltage measurement on a pin of the device is described in *Figure 17*.

Figure 16. Pin loading conditions

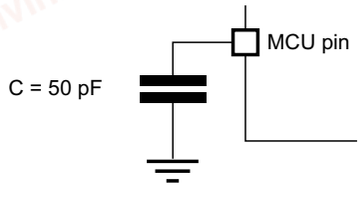
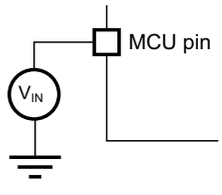


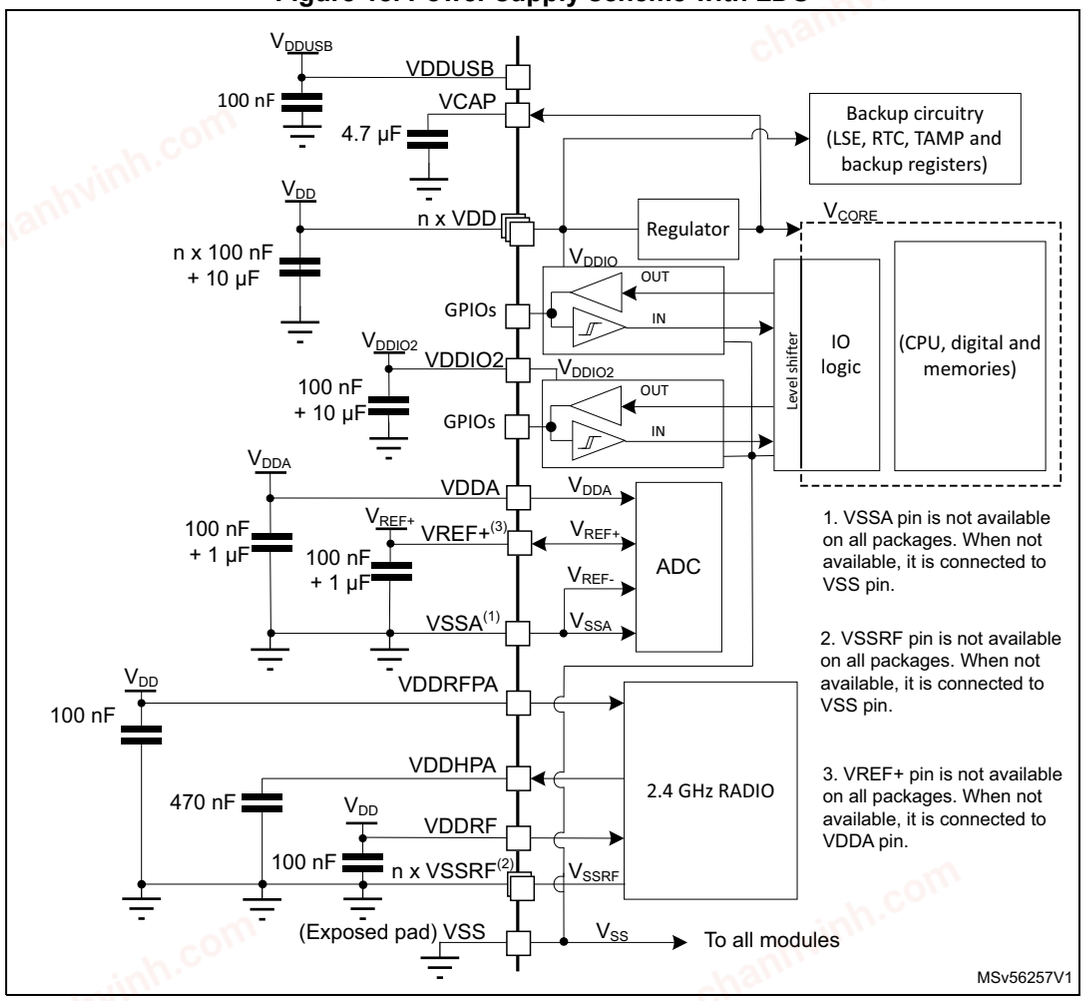
Figure 17. Pin input voltage



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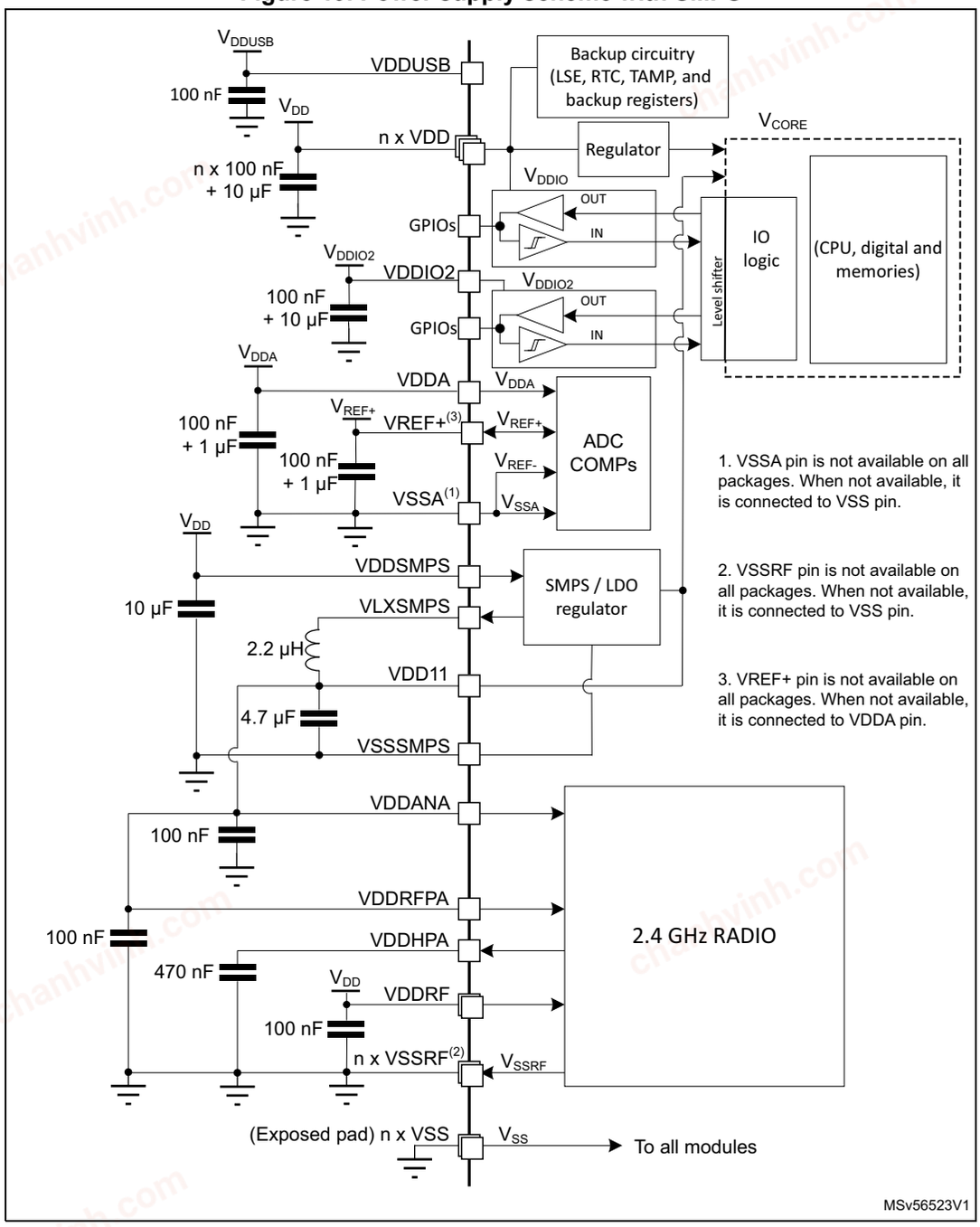
5.1.6 Power supply scheme

Figure 18. Power supply scheme with LDO



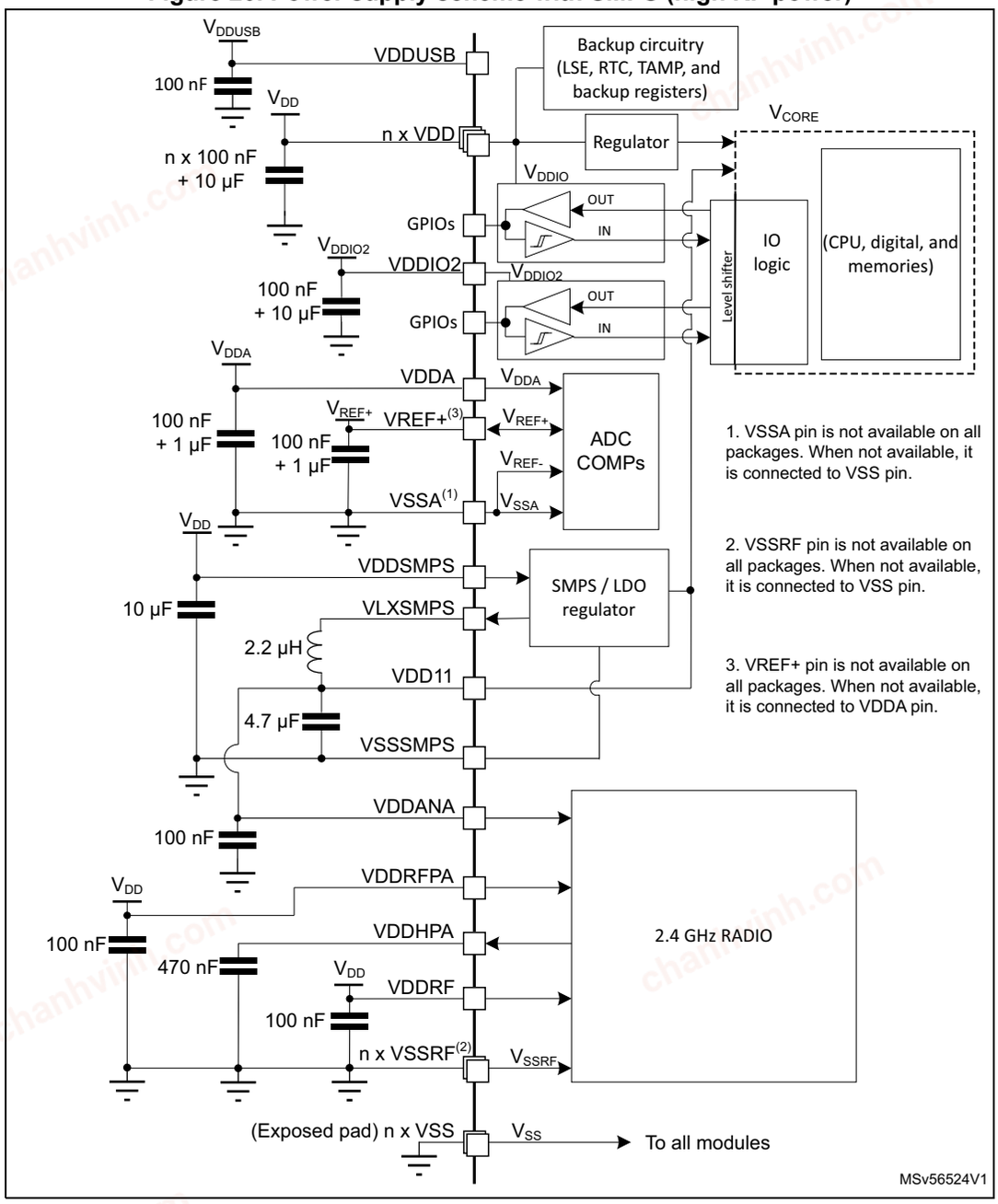
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Figure 19. Power supply scheme with SMPS



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Figure 20. Power supply scheme with SMPS (high RF power)



Caution: Each power supply pair (V_{DD} / V_{SS}, V_{DDA} / V_{SS}, V_{DDRFPA} / V_{SS}, V_{DDRF} / V_{SS}) must be decoupled with filtering ceramic capacitors as shown. These capacitors must be placed as close as possible to (or below) the appropriate pins to ensure correct device functionality.

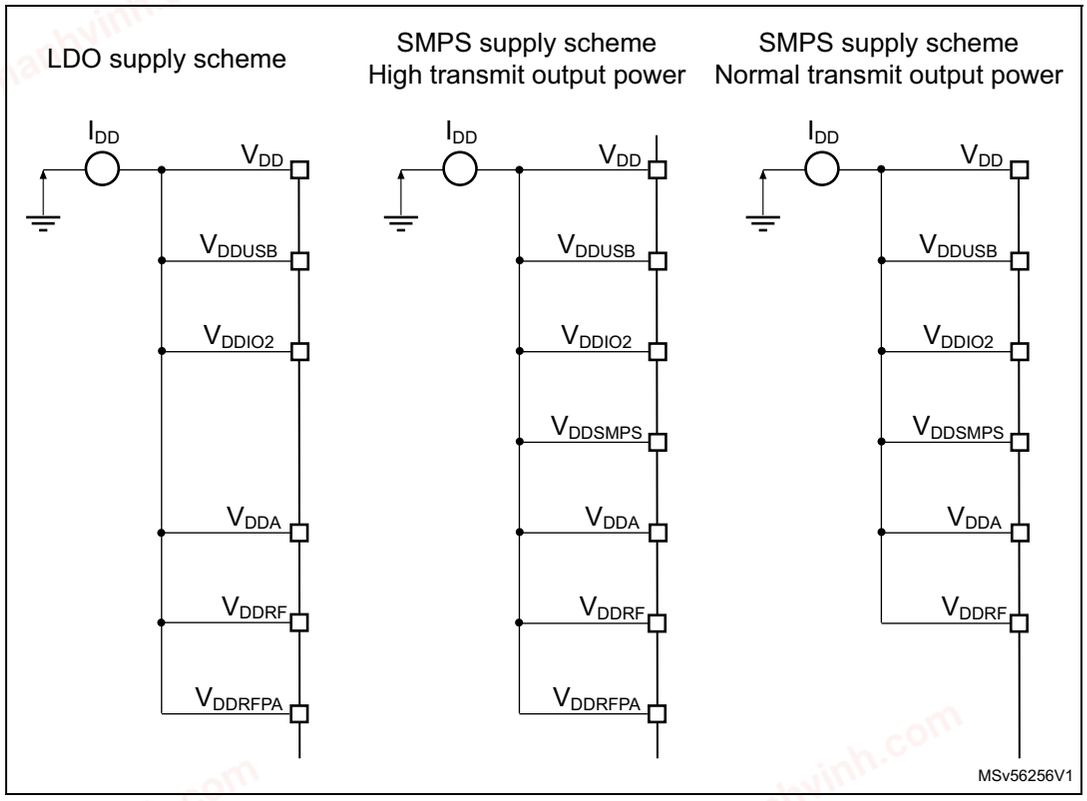
Caution: V_{DD} and V_{DDRF} must be connected to the same supply.

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5.1.7 Current consumption measurement

The I_{DD} parameters in the tables in the next sections represent the total MCU consumption, including the current supplying V_{DD}, V_{DDIO2}, V_{DDUSB}, V_{DDA}, V_{DDRF}, V_{DDRFPA}, and V_{DDSMPS} (if the device embeds the SMPS), or the total 2.4 GHz RADIO current supplying V_{DDRF} and V_{DDRFPA}.

Figure 21. Current consumption measurement scheme



5.2 Absolute maximum ratings

Stresses above the absolute maximum ratings listed in *Table 26*, *Table 27*, and *Table 28* can cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these conditions is not implied. Exposure to maximum rating conditions for extended periods can affect device reliability. Device mission profile (application conditions) is compliant with JEDEC JESD47 Qualification Standard, extended mission profiles are available on demand.

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Table 26. Voltage characteristics(1)

Symbol	Ratings	Min	Max	Unit
V_{DDX} - V_{SS}	External main supply voltage (including V_{DDUSB}, V_{DDA}, V_{DDRF}, V_{DDRFPA}, V_{DDANA}, V_{DDSMPS})	-0.3	4.0	V
V_{DDIOX} - V_{SS}	I/O supply when HSLV = 0 (including V_{DD}, V_{DDIO2})		4.0	
	I/O supply when HSLV = 1 (including V_{DD}, V_{DDIO2})		2.75	
V_{IN}(2)	Input voltage on FT_ (any option) pins	V_{SS} - 0.3	min (min (V_{DD}, V_{DDIO2}, V_{DDUSB}, V_{DDA}) + 4.0, 6.0)(3)(4)	
	Input voltage on any other pin		4.0	
$\lvert\Delta V_{DDx}\rvert$	Variations between different VDDX power pins of the same domain	-	50.0	mV
$\lvert V_{SSx}-V_{SS}\rvert$	Variations between all the different ground pins	-	50.0	

1. All main power (VDD, VDDIO2, VDDUSB, VDDA, VDDRF, VDDRFPA, VDDANA, VDDSMPS) and ground (VSS, VSSA, VSSRF, VSSSMPS) pins must always be connected to the external power supply, in the permitted range.
2. V_{IN} maximum must always be respected. Refer to *Table 27* for the maximum allowed injected current values.
3. To sustain a voltage higher than 4 V, the internal pull-up/pull-down resistors must be disabled.
4. This formula applies only to power supplies related to the I/O structure described by the pin definition table.

Table 27. Current characteristics

Symbol	Ratings	Max	Unit
$\sum I_{VDD}$	Total current into sum of all V_{DD} power lines (source)(1)	200	mA
$\sum I_{VSS}$	Total current out of sum of all V_{SS} ground lines (sink)(1)	200	
$I_{VDD(PIN)}$	Maximum current into each VDD power pin (source)(1)	100	
$I_{VSS(PIN)}$	Maximum current out of each VSS ground pin (sink)(1)	100	
I_{IO}	Output current sunk by any I/O and control pin	20	
$\sum I_{(PIN)}$	Total output current sunk by sum of all I/Os and control pins(2)	120	
	Total output current sourced by sum of all I/Os and control pins(2)	120	
$I_{INJ(PIN)}$(3)(4)	Injected current on FT_xxx, TT_xx, RST pins	-5/+0	
$\sum\lvert I_{INJ(PIN)}\rvert$	Total injected current (sum of all I/Os and control pins)(5)	±25	

1. All main power (VDD, VDDIO2, VDDUSB, VDDA, VDDRF, VDDRFPA, VDDANA, VDDSMPS) and ground (VSS, VSSA, VSSRF, VSSSMPS) pins must always be connected to the external power supplies, in the permitted range.
2. This current consumption must be correctly distributed over all I/Os and control pins. The total output current must not be sunk/sourced between two consecutive power supply pins.
3. Positive injection (when $V_{IN} > V_{DD}$) is not possible on these I/Os and does not occur for input voltages lower than the specified maximum value.
4. A negative injection is induced by $V_{IN} < V_{SS}$. $I_{INJ(PIN)}$ must never be exceeded. Refer also to *Table 26* for the maximum allowed input voltage values.
5. When several inputs are submitted to a current injection, the maximum $\sum\lvert I_{INJ(PIN)}\rvert$ is the absolute sum of the negative injected currents (instantaneous values).

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Table 28. Thermal characteristics

Symbol	Ratings	Value	Unit
T_{STG}	Storage temperature range	–65 to +150	°C
T_{JMAX}	Maximum junction temperature	140	

5.3 Operating conditions

5.3.1 Summary of main performance

Table 29. Main performance at V_{DD} = 3.3 V

Parameter			Test conditions	Typ	Unit
I_{DD}	Core current consumption		Standby (64 Kbytes RAM retention)	1.15	µA
			Stop 1	9.67	
			Stop 2	5.30	
			Sleep (V_{DD} = 3.0 V, 16 MHz)	0.25	mA
			Run (100 MHz)	4.40	
			Radio BLE Rx 1 Mbps(1)	4.26	
			Radio BLE Tx 0 dBm output power(1)	5.94	
I_{DD}	Peripheral current consumption	BLE	Advertising using Standby mode(2) (Tx = 0 dBm; Period 1.28 s; 31 bytes, 3 channels)	13.334	µA
			Advertising using Standby mode(2) (Tx = 0 dBm, 6 bytes; period 10.24 s, 3 channels)	4.544	

1. Power consumption including RF subsystem and digital processing.
2. Power consumption integrated over 100 s, including Cortex-M33, 2.4 GHz RADIO subsystem and digital processing.

5.3.2 General operating conditions

Table 30. General operating conditions

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DD}	Standard operating voltage	V_{DD} GPIO HSLV = 0	1.71(1)	-	3.6	V
		V_{DD} GPIO HSLV = 0		-	2.75	
V_{DDIO2}	Supply voltage for PG I/O port	V_{DDIO2} GPIO HSLV = 0	1.08	-	3.6	V
		V_{DDIO2} GPIO HSLV = 1		-	2.75	
V_{DDUSB}	USB supply voltage	USB used	3.0	-	3.6	V
		USB not used	0	-		
V_{DDSMPS}	Supply voltage for internal SMPS step-down converter	-	V_{DD}			V

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Table 30. General operating conditions (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DDA}	Analog supply voltage	ADC used	1.62	-	3.6	V
		COMP used	1.58	-		
		ADC, COMP not used	0	-		
V_{DDRF}	RF operating voltage	-	1.71	-	3.6	V
V_{DDRFPA}	RF power amplifier operating voltage	V_{DDRFPA} supply must be equal or lower than V_{DDRF}.	1.15	-	3.6	V
V_{DDANA}	RF analog supply	V_{DDANA} supply must be equal or lower than V_{DDRF}.	1.15	-	3.6	V
V_{IN}	I/O input voltage	All I/Os FT_ (any option) pins	-0.3	-	min (min (V_{DD}, V_{DDIO2}, V_{DDA}) + 3.6, 5.5)(2)(3)	
		TT I/O pins			V_{DD} + 0.3	
V_{CORE}	Internal regulator ON	Range 1	1.15	1.21	1.27	
		Range 2	0.81	0.90	0.99	
f_{HCLK}	Internal AHB1, AHB2, and AHB4 clock frequency	Range 1	-	-	100	MHz
		Range 2	-	-	16	
f_{PCLK}	Internal APB1, APB2, and APB7 clock frequency	Range 1	-	-	100	
		Range 2	-	-	16	
f_{HCLK5}	Internal AHB5 clock frequency	Range 1	-	-	32	
		Range 2	-	-	12	
Δf_{HCLK1}	Internal AHB1, AHB2 and AHB4 clock incremental frequency step(4)	-	-	-	84	MHz
P_D	Power dissipation at T_A = 85 °C (suffix 6 version) or T_A = 105 °C (suffix 7 version)	See *Section 6.6* for appropriate thermal resistance and package. Power dissipation is calculated according to ambient temperature (T_A), maximum junction temperature (T_J), and selected thermal resistance.				mW
T_A	Ambient temperature (suffix 6 version)	Max power dissipation	–40	-	85	°C
		Low-power dissipation(5)			105	
	Ambient temperature (suffix 7 version)	Max power dissipation	–40	-	105	
		Low-power dissipation(5)			125	
T_J	Junction temperature range	Suffix 6 version	–40	-	105	°C
		Suffix 7 version(6)			125	

1. When RESET is released functionality is guaranteed down to V_{BORx} min.
2. Applies only on the power supplies related to the I/O structure described by the pin definition table. The maximum I/O input voltage is the smallest value between min (V_{DD}, V_{DDIO2}, V_{DDA}, V_{DDUSB}) +3.6 V and 5.5 V.
3. For operation with voltages higher than min (V_{DD}, V_{DDIO2}, V_{DDA}, V_{DDUSB}) +3.6 V the internal pull-up and pull-down resistors must be disabled.
4. Without system clock frequency step limiting.

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5. In low-power dissipation state, T_A can be extended to this range as long as T_J does not exceed T_J max (see *Section 6.6*).
6. Junction temperature above 105 °C must be limited to 30% of 10 years life time.

5.3.3 RF characteristics

Table 31. Generic RF transmitter characteristics(1)

Symbol	Parameter		Test conditions	Standard	Min	Typ	Max	Unit
P_{txmax}	Maximum output power		V_{DDRFPA} ≥ 2.50 V	-	-	9.5	-	dBm
			V_{DDRFPA} ≥ 1.71 V	-	-	7.5	-	
P_{txmin}	Minimum output power		-	-	-	-20	-	
ΔP_{tx}	Output power step		-	-	-	1	-	dB
$P_{freqband}$	Output power ± variation over the frequency band		P_{txmax} max setting	-	-	0.4	-	
P_{temp}	Output power ± variation over the temperature		P_{txmax} max setting -40 °C ≤ T_J ≤ +105 °C	-	-	2.9	-	
$P_{2ndHARM}$	Second harmonic		P_{txmax} max setting	-	-	-69.5	-	dBm
$P_{3rdHARM}$	Third harmonic		P_{txmax} max setting	-	-	-70.5	-	
$OBSE_{1Mbps}$	Out of band spurious emission 1 Mbps	< 1 GHz	P_{txmax} max setting	(2)	-	-51	-	
		≥ 1 GHz	P_{txmax} max setting		-	-43	-	
$OBSE_{2Mbps}$	Out of band spurious emission 2 Mbps	< 1 GHz	P_{txmax} max setting	(2)	-	-54	-	
		≥ 1 GHz	P_{txmax} max setting		-	-45	-	

1. Evaluated by characterization, not tested in production, unless otherwise specified. Measured in conducted mode, based on reference design (see AN5165), using output power specific external RF filter and impedance matching networks to interface with a 50 Ω antenna.
2. Suitable for systems targeting compliance with worldwide radio-frequency regulations ETSI EN 300 328 and EN 300 440 Class 2 (Europe), FCC CFR47 Part 15 (US), and ARIB STD-T66 (Japan).

Table 32. Generic RF receiver characteristics(1)

Symbol	Parameter	Test conditions	Standard	Min	Typ	Max	Unit
$Rssi_{max}$	RSSI maximum value	-	-	-	-32	-	dBm
$Rssi_{min}$	RSSI minimum value	-	-	-	-75	-	
$Rssi_{accu}$	RSSI accuracy	-	-	-	±6	-	dB

1. Evaluated by characterization, not tested in production, unless otherwise specified. Measured in conducted mode, based on reference design (see AN5165), using output power specific external RF filter and impedance matching networks to interface with a 50 Ω antenna.

Table 33. RF Bluetooth Low Energy characteristics

Symbol	Parameter	Test conditions	Min	Typ	Max	Unit
F_{op}	Frequency channel operating band	-	2402	-	2480	MHz
ΔF	Delta frequency	-	-	250	-	kHz

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Table 33. RF Bluetooth Low Energy characteristics (continued)

Symbol	Parameter	Test conditions	Min	Typ	Max	Unit
Rgfsk	On air data rate	-	0.125	-	2	Mbps
PLLres	RF channel spacing	-	-	2	-	MHz

Table 34. RF transmitter Bluetooth Low Energy characteristics(1)

Symbol	Parameter		Test conditions	Standard	Min	Typ	Max	Unit
$BW6dB_{1Mbps}$	6 dB signal bandwidth		P_{txmax} max setting	-	-	665	-	kHz
$BW6dB_{2Mbps}$	6 dB signal bandwidth		P_{txmax} max setting	-	-	1142	-	
$IBSE_{1Mbps}$	In band spurious emission	2 MHz	-	-20	-	-41	-20	dBm
		≥ 3 MHz	-	-30	-	-47.5	-30	
$IBSE_{2Mbps}$	In band spurious emission	4 MHz	-	-20	-	-42.5	-20	dBm
		5 MHz	-	-20	-	-44	-20	
		≥ 6 MHz	-	-30		-45	-30	
f_d	Frequency drift		-	±50	-50	-	+50	kHz
dr_{max}	Maximum drift rate	Uncoded	-	±20	-20	-	+20	kHz/ 50 µs
		Coded	-	±19.2	-19.2	-	+19.2	
fo	Frequency offset		-	±150	-150	-	+150	kHz
$\Delta f1_{1Mbps}$	Frequency deviation average 1 Mbps		-	225 - 275	225	-	275	
$\Delta f1_{2Mbps}$	Frequency deviation average 2 Mbps		-	450 - 550	450	-	550	
$\Delta f1_{CodedS8}$	Frequency deviation average Coded S = 8		-	225 - 275	225	-	275	
$\Delta f2_{1Mbps}$	Frequency deviation 99.9% 1 Mbps		-	185	185	-	-	
$\Delta f2_{2Mbps}$	Frequency deviation 99.9% 2 Mbps		-	370	370	-	-	

1. Evaluated by characterization, not tested in production, unless otherwise specified. Measured in conducted mode, based on reference design (see AN5165), using output power specific external RF filter and impedance matching networks to interface with a 50 Ω antenna.

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Table 35. RF receiver Bluetooth Low Energy characteristics (1)

Symbol	Parameter	Test conditions	Standard	Min	Typ	Max	Unit
P_{rxmax}	Maximum input signal	PER ≤ 30.8%	-10	-	6	-	dBm
$P_{sens2Mbps}$ (2)	Sensitivity 2 Mbps	SMPS bypass (3)	-70	-	-93	-	
		SMPS on (3)		-		-	
$P_{sens1Mbps}$ (2)	Sensitivity 1 Mbps	SMPS bypass (3)	-70	-	-96	-	
		SMPS on (3)		-		-	
$P_{sens500kbps}$ (2)	Sensitivity 500 kbps	SMPS bypass (3)	-75	-	-99	-	
		SMPS on (3)		-		-	
$P_{sens125kbps}$ (2)	Sensitivity 125 kbps	SMPS bypass (3)	-82	-	-102	-	
		SMPS on (3)		-		-	
$P_{IMD1Mbps}$	Intermodulation 1 Mbps	|f2 - f1| = 3 MHz	-50	-50	-37	-	
		|f2 - f1| = 4 MHz		-50	-27	-	
		|f2 - f1| = 5 MHz		-50	-28	-	
$P_{OBB1Mbps}$	Out of band blocking (for desired signal at -67 dBm and 1 Mbps)	30 to 2000 MHz	-30	-30	-10	-	
		2000 to 2399 MHz	-35	-35	-22	-	
		2484 to 2999 MHz	-35	-35	-15	-	
		3 to 12.75 GHz	-30	-30	-10	-	
$P_{IMD2Mbps}$	Intermodulation 2 Mbps	|f2 - f1| = 3 MHz	-50	-50	-37	-	dBm
		|f2 - f1| = 4 MHz		-50	-30	-	
		|f2 - f1| = 5 MHz		-50	-30	-	
$P_{OBB2Mbps}$	Out of band blocking (for desired signal at -67 dBm and 2 Mbps)	30 to 2000 MHz	-30	-30	-10	-	
		2000 to 2399 MHz	-35	-35	-33	-	
		2484 to 2999 MHz	-35	-35	-19	-	
		3 to 12.75 GHz	-30	-30	-10	-	

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Table 35. RF receiver Bluetooth Low Energy characteristics (1) (continued)

Symbol	Parameter	Test conditions	Standard	Min	Typ	Max	Unit
$C/Ico_{125kbps}$	Co-channel rejection 125 kbps	-	12	-	3	-	dB
$C/I_{125kbps}$	Adjacent channel interference 125 kbps	Adj = ±1 MHz	6	-	-2	6	
		Adj = 2 MHz	-26	-	-38	-26	
		Adj-Image = -2 MHz	-18	-	-27	-18	
		Adj ≥ 3 MHz	-36	-	-43	-36	
		Adj = -3 MHz	-24	-	-28	-24	
		Adj ≤ -4 MHz	-36	-	-43	-36	
$C/Ico_{250kbps}$	Co-channel rejection 250 kbps	-	17	-	5	17	
$C/I_{500kbps}$	Adjacent channel interference 500 kbps	Adj = ±1 MHz	11	-	-2	11	
		Adj = 2 MHz	-21	-	-34	-21	
		Adj-Image = -2 MHz	-13	-	-26	-13	
		Adj ≥ 3 MHz	-31	-	-39	-31	
		Adj = -3 MHz	-19	-	-27	-19	
		Adj ≤ -4 MHz	-31	-	-37	-31	
C/Ico_{1Mbps}	Co-channel rejection 1 Mbps	-	21	-	8	21	
C/I_{1Mbps}	Adjacent channel interference 1 Mbps	Adj = ±1 MHz	15	-	0	15	
		Adj = 2 MHz	-17	-	-38	-17	
		Adj-Image = -2 MHz	-9	-	-23	-9	
		Adj ≥ 3 MHz	-27	-	-36	-27	
		Adj = -3 MHz	-15	-	-27	-15	
		Adj ≤ -4 MHz	-27	-	-38	-27	
C/Ico_{2Mbps}	Co-channel rejection 2 Mbps	-	21	-	8	21	
C/I_{2Mbps}	Adjacent channel interference 2 Mbps	Adj = ±2 MHz	15	-	0	15	dB
		Adj = 4 MHz	-17	-	-35	-17	
		Adj-Image = -4 MHz	-9	-	-23	-9	
		Adj = ≥ 6 MHz	-27	-	-33	-27	
		Adj = -6 MHz	-15	-	-26	-15	
		Adj = ≤ -8 MHz	-27	-	-34	-27	

1. Evaluated by characterization, not tested in production, unless otherwise specified. Measured in conducted mode, based on reference design (see AN5165), using output power specific external RF filter and impedance matching networks to interface with a 50 Ω antenna.
2. With ideal transmitter.
3. The payload length used in all receiver tests is 37 bytes which means that the limit for each parameter is reached for a BER of 0.1% (PER of 30.8%), as defined in the Bluetooth core specification v5.4.

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Table 36. RF Bluetooth Low Energy power consumption for V_{DD} = 3.3 V(1)(2)

Symbol	Parameter	Typ	Unit
I_{tx}	Tx 0 dBm output power consumption (LDO)	11.39	mA
	Tx 0 dBm output power consumption (SMPS ON, VDDRFPA connected to VDD)	6.16	
	Tx 0 dBm output power consumption (SMPS ON, VDDRFPA connected to VDD11)	5.94	
	Tx +10 dBm output power consumption (LDO)	22.38	
	Tx +10 dBm output power consumption (SMPS ON, VDDRFPA connected to VDD)	21.18	
I_{rx}	Rx consumption 1 Mbps (LDO)	7.83	
	Rx consumption 1 Mbps (SMPS ON, VDDRFPA connected to VDD)	5.33	
	Rx consumption 1 Mbps (SMPS ON, VDDRFPA connected to VDD11)	4.26	
	Rx consumption 2 Mbps (LDO)	8.53	
	Rx consumption 2 Mbps (SMPS ON, VDDRFPA connected to VDD)	8	
	Rx consumption 2 Mbps (SMPS ON, VDDRFPA connected to VDD11)	5	

1. Evaluated by characterization, not tested in production, unless otherwise specified.
2. Power consumption including 2.4 GHz RADIO subsystem and digital processing.

5.3.4 RF IEEE802.15.4 characteristics

Table 37. RF IEEE802.15.4 characteristics(1)

Symbol	Parameter	Conditions	Standard	Min	Typ	Max	Unit
F_{op}	Frequency channel operating band	-	-	2405	-	2480	MHz
ΔF	Delta frequency	-	-	-	5	-	
Roqpsk	On air data rate	-	-		250	-	kbps
PLLres	RF channel spacing	-	-	-	5	-	MHz

1. Guaranteed by characterization results, unless otherwise specified. Measured in conducted mode, based on reference design (see AN5165), using output power specific external RF filter and impedance matching networks to interface with a 50 Ω antenna.

Table 38. RF transmitter IEEE802.15.4 characteristics(1)

Symbol	Parameter	Test conditions	Standard	Min	Typ	Max	Unit
P_{txmax}	Maximum output power	V_{DDRFPA} ≥ 2.50 V	-	-	9.5	-	dBm
		V_{DDRFPA} ≥ 1.71 V	-	-	7.5	-	
P_{txmin}	Minimum output power	-	-	-	-15	-	
ΔP_{tx}	Output power step	-	-	0.5	1	2	dB
$P_{freqband}$	Output power ± variation over the frequency band	P_{txmax} max setting	-	-	0.5	-	
P_{temp}	Output power ± variation over the temperature	P_{txmax} max setting -40 °C ≤ T_J ≤ +130 °C	-	-	2.5	-	

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Table 38. RF transmitter IEEE802.15.4 characteristics(1) (continued)

Symbol	Parameter	Test conditions	Standard	Min	Typ	Max	Unit
$P_{2ndHARM}$	Second harmonic	P_{txmax} max setting	-	-	-69.5	-	dBm
$P_{3rdHARM}$	Third harmonic	P_{txmax} max setting	-	-	-70.5	-	

1. Evaluated by characterization, not tested in production, unless otherwise specified. Measured in conducted mode, based on reference design (see AN5165), using output power specific external RF filter and impedance matching networks to interface with a 50 Ω antenna.

Table 39. RF receiver IEEE802.15.4 characteristics(1)

Symbol	Parameter	Conditions	Standard	Min	Typ	Max	Unit
P_{rxmax}	Maximum input signal	PER ≤ 1%	-20	-	-20	-	dBm
$P_{sens250kbps}$	Sensitivity 250 kbps (LDO)	PER ≤ 1%	-85	-	-98	-	
	Sensitivity 250 kbps (SMPS ON)		-85	-	-98	-	
C/I_{adj}	Adjacent channel rejection	-	0	-	10	-	dB
C/I_{alt}	Alternate channel rejection	-	30	-	30	-	

1. Guaranteed by characterization results, unless otherwise specified. Measured in conducted mode, based on reference design (see AN5165), using output power specific external RF filter and impedance matching networks to interface with a 50 Ω antenna.

Table 40. RF IEEE802.15.4 power consumption for V_{DD} = 3.3 V(1)(2)

Symbol	Parameter	Typ	Unit
I_{tx}	Tx 0 dBm output power consumption (LDO)	15.37	mA
	Tx 0 dBm output power consumption (SMPS ON, VDDRFPA connected to VDD)	7.84	
	Tx 0 dBm output power consumption (SMPS ON, VDDRFPA connected to VDD11)	7.62	
	Tx +10 dBm output power consumption (LDO)	28.39	
	Tx +10 dBm output power consumption (SMPS ON, VDDRFPA connected to VDD)	25.48	
I_{rx}	Rx consumption (LDO)	11.31	
	Rx consumption (SMPS ON, VDDRFPA connected to VDD)	6.99	
	Rx consumption (SMPS ON, VDDRFPA connected to VDD11)	5.95	

1. Guaranteed by characterization results, unless otherwise specified.
2. Power consumption including 2.4 GHz RADIO subsystem and digital processing.

5.3.5 Operating conditions at power-up/power-down

The parameters in *Table 41* are evaluated by characterization under ambient temperature and supply voltage conditions summarized in *Table 30*.

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Table 41. Operating conditions at power-up / power-down(1)

Symbol	Parameter	Conditions	Min	Max	Unit
t_{VDD}	V_{DD} rise time rate	-	0	∞	µs/V
	V_{DD} fall time rate	ULPMEN = 0	20	∞	
		Standby mode with ULPMEN = 1	250	∞	ms/V

1. Evaluated by characterization, not tested in production, unless otherwise specified.

5.3.6 Embedded reset and power control block characteristics

The parameters in *Table 42* are derived under ambient temperature and supply voltage conditions summarized in *Table 30*.

Table 42. Embedded reset and power control block characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$t_{RSTTEMPO}$(1)	Reset temporization after V_{BOR0} threshold detection	V_{DD} rising	-	-	900	µs
V_{BOR0}(2)	Brown-out reset threshold 0	V_{DD} rising	1.60	1.66	1.71	V
		V_{DD} falling	1.58	1.64	1.69	
V_{BOR1}(2)	Brown-out reset threshold 1	V_{DD} rising	1.98	2.08	2.17	
		V_{DD} falling	1.90	2.00	2.10	
V_{BOR2}(2)	Brown-out reset threshold 2	V_{DD} rising	2.18	2.29	2.39	
		V_{DD} falling	2.08	2.18	2.25	
V_{BOR3}(2)	Brown-out reset threshold 3	V_{DD} rising	2.48	2.59	2.70	
		V_{DD} falling	2.39	2.50	2.61	
V_{BOR4}(2)	Brown-out reset threshold 4	V_{DD} rising	2.76	2.88	3.00	
		V_{DD} falling	2.67	2.79	2.90	

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Table 42. Embedded reset and power control block characteristics (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{PVD0}(2)	Programmable voltage detector threshold 0	V_{DD} rising	2.03	2.13	2.23	V
		V_{DD} falling	1.93	2.03	2.12	
V_{PVD1}(2)	PVD threshold 1	V_{DD} rising	2.18	2.29	2.39	
		V_{DD} falling	2.08	2.18	2.28	
V_{PVD2}(2)	PVD threshold 2	V_{DD} rising	2.33	2.44	2.55	
		V_{DD} falling	2.23	2.34	2.44	
V_{PVD3}(2)	PVD threshold 3	V_{DD} rising	2.47	2.59	2.70	
		V_{DD} falling	2.39	2.50	2.61	
V_{PVD4}(2)	PVD threshold 4	V_{DD} rising	2.60	2.72	2.83	
		V_{DD} falling	2.50	2.62	2.73	
V_{PVD5}(2)	PVD threshold 5	V_{DD} rising	2.76	2.88	3.00	
		V_{DD} falling	2.66	2.78	2.90	
V_{PVD6}(2)	PVD threshold 6	V_{DD} rising	2.83	2.96	3.08	
		V_{DD} falling	2.76	2.88	3.00	
V_{hyst_BOR0}(2)	BOR0 hysteresis voltage	-	-	20	-	mV
$V_{hyst_BOR_PVD}$(2)	BOR1, 2, 3, 4 and PVD hysteresis voltage	-	-	80	-	
$t_{sampling_BOR0}$(2)	BOR0 ultra-low-power sampling monitoring period	ULPEN = 1	-	12	30	ms
$I_{DD_BOR_PVD}$(1)	BOR1, 2, 3, 4 and PVD consumption from V_{DD}, and additional BOR0 consumption for ULPMEN = 0 vs. ULPMEN = 1 (3)	-	-	1.7	2.5	µA

1. Specified by design, not tested in production.
2. Evaluated by characterization, not tested in production.
3. BOR0 is enabled in all modes, its consumption is therefore included in the supply current characteristics tables.

5.3.7 Embedded voltage reference

The parameters in *Table 43* are derived under ambient temperature and supply voltage conditions summarized in *Table 30*.

Table 43. Embedded internal voltage reference

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{REFINT}(1)	Internal reference voltage	Range 1	1.175	1.215	1.255	V
		Range 2 and low-power modes	1.170	1.215	1.260	-
$t_{S_vrefint}$(2)(3)	ADC sampling time when reading the internal reference voltage	-	4	-	-	µs
$t_{start_vrefint}$(3)	Start time of reference voltage buffer when ADC is enabled	-	-	4	6	-

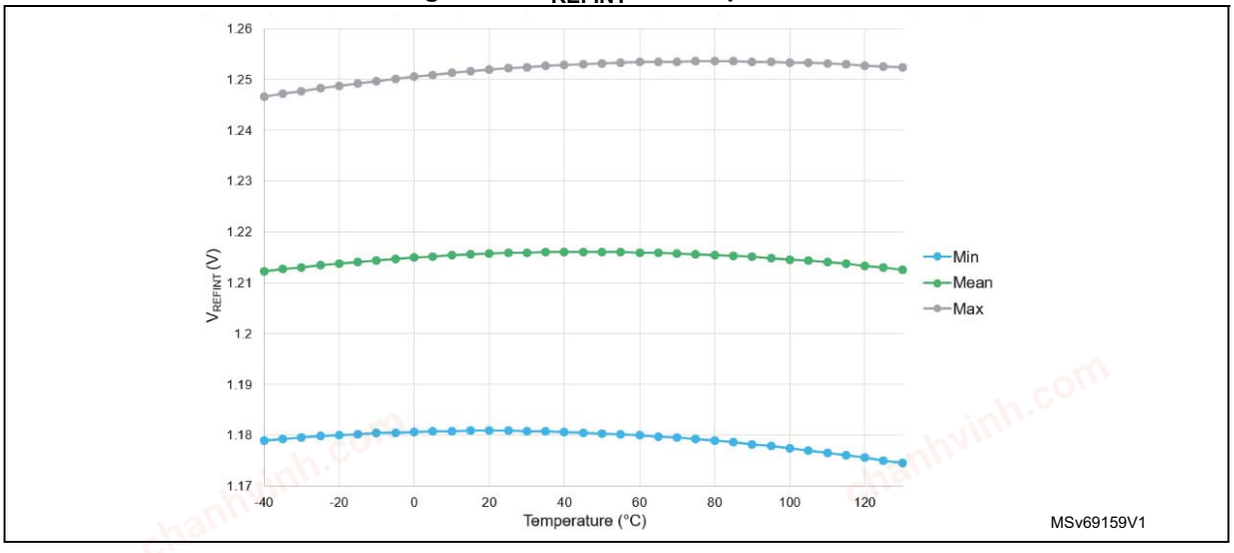
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Table 43. Embedded internal voltage reference (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$I_{DD(VREFINTBUF)}$(3)	V_{REFINT} buffer consumption from V_{DD} when converted by ADC	-	-	1.5	2.1	µA
ΔV_{REFINT}(4)	Internal reference voltage spread over the temperature range	V_{DD} = 3 V	-	6	11.5	mV
T_{Coeff}(4)	Average temperature coefficient	–40 °C ≤ T_J ≤ +130 °C	-	40	125	ppm/°C
A_{Coeff}(3)	Long term stability	1000 hours, T_J = 25 °C	-	400	1000	ppm
$V_{DDCoeff}$(4)	Voltage coefficient	3.0 V ≤ V_{DD} ≤ 3.6 V	-	500	2900	ppm/V

1. V_{REFINT} does not take into account package and soldering effects.
2. The shortest sampling time for the application can be determined by multiple iterations.
3. Specified by design, not tested in production.
4. Evaluated by characterization, not tested in production.

Figure 22. V_{REFINT} vs. temperature



5.3.8 Supply current characteristics

The current consumption is measured as described in *Section 5.1.7*. It depends upon several parameters, such as operating voltage, ambient temperature, I/O pin loading, device software configuration, operating frequency, I/O pin switching rate, program location in memory, and executed binary code.

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Typical and maximum current consumption

The MCU is put under the following conditions:

- All I/O pins are in analog input mode
- All peripherals are disabled, except when otherwise mentioned
- The flash memory and SRAM access time is adjusted with the minimum wait states number, depending upon the f_{HCLK} frequency (refer to tables in the reference manual).
- When the peripherals are enabled $f_{PCLKx} = f_{HCLK1}$
- The voltage scaling is adjusted to f_{HCLK} frequency as follows:
  - Voltage range 1 for 16 MHz < f_{HCLK1} ≤ 100 MHz and 12 MHz < f_{HCLK5} ≤ 32 MHz
  - Voltage range 2 for f_{HCLK1} ≤ 16 MHz and f_{HCLK5} ≤ 12 MHz

The parameters given in *Table 44* and *Table 45* are evaluated by characterization under ambient temperature and supply voltage conditions summarized in *Table 30*.

Table 44. Current consumption in Run modes on LDO, code with data processing running from flash memory, Cache ON (1-way), prefetch OFF, V_{DD} = 3.3 V(1)(2)(3)

Symbol	Parameter	Conditions			Typ			Unit
		-	Voltage scaling	f_{HCLK1}	25 °C	55 °C	85 °C	
$I_{DD(Run)}$	Supply current in Run mode	$f_{HCLK1} = f_{HSI16}$ = 16 MHz	Range 2	16 MHz	1.11	1.18	1.40	mA
		$f_{HCLK1} = f_{HSE32}$ = 32 MHz	Range 1	32 MHz	3.03	3.19	3.57	
		f_{HCLK1} = HSE32 + PLL > 32 MHz		100 MHz	7.76	7.94	8.35	

1. Evaluated by characterization, not tested in production, unless otherwise specified.
2. Reduced code used for characterization.
3. All peripherals disabled, SRAM1 and SRAM2 enabled.

Table 45. Current consumption in Run modes on SMPS, code with data processing running from flash memory, Cache ON (1-way), prefetch OFF, V_{DD} = 3.3 V(1)(2)(3)

Symbol	Parameter	Conditions			Typ			Unit
		-	Voltage scaling	f_{HCLK1}	25 °C	55 °C	85 °C	
$I_{DD(Run)}$	Supply current in Run mode	$f_{HCLK1} = f_{HSI16}$ = 16 MHz	Range 2	16 MHz	0.56	0.59	0.68	mA
		$f_{HCLK1} = f_{HSE32}$ = 32 MHz	Range 1	32 MHz	2.01	2.12	2.35	
		f_{HCLK1} = HSE32 + PLL > 32 MHz		100 MHz	4.40	4.53	4.77	

1. Guaranteed by characterization results, unless otherwise specified.
2. Reduced code used for characterization results
3. All peripherals disabled, SRAM1 and SRAM2 enabled.

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Table 46. Current consumption in Run mode on LDO, with different codes running from flash memory, Cache ON (2-way), Prefetch OFF(1)

Symbol	Parameter	Conditions			Typ			Unit	Typ			Unit
					25 °C				25 °C			
		-	Voltage scaling	Code	1.8 V	3.0 V	3.3 V		1.8 V	3.0 V	3.3 V	
$I_{DD(Run)}$	Supply current in Run mode	All peripherals disabled, SRAM1 and SRAM2 enabled	Range 2, $f_{HCLK1} = f_{HSI16}$ = 16 MHz	Reduced code	1.16	1.16	1.16	mA	72.68	72.50	72.58	µA/MHz
				Coremark®	1.17	1.17	1.18		73.13	73.38	73.50	
				SecureMark	1.22	1.22	1.22		76.25	76.13	76.19	
				Dhrystone 2.1	1.23	1.23	1.23		76.88	76.88	76.94	
				Fibonacci	1.11	1.11	1.12		69.38	69.38	69.69	
				While(1)	0.85	0.85	0.85		53.00	52.96	52.98	
			Range 1, $f_{HCLK1} = f_{HSE32}$ = 32 MHz	Reduced code	3.09	3.16	3.17		96.54	98.64	99.19	
				Coremark®	3.12	3.19	3.20		97.50	99.69	100.00	
				SecureMark	3.32	3.38	3.40		103.59	105.63	106.25	
				Dhrystone 2.1	3.31	3.37	3.39		103.44	105.31	105.94	
				Fibonacci	2.96	3.03	3.05		92.50	94.69	95.31	
				While(1)	2.30	2.37	2.39		71.88	74.06	74.69	
			Range 1, f_{HCLK1} = HSE32 + PLL at 100 MHz	Reduced code	8.14	8.21	8.23		81.44	82.08	82.26	
				Coremark®	8.24	8.30	8.32		82.40	83.00	83.20	
				SecureMark	8.73	8.79	8.81		87.30	87.90	88.10	
				Dhrystone 2.1	8.83	8.89	8.91		88.30	88.90	89.10	
				Fibonacci	7.74	7.80	7.82		77.40	78.00	78.20	
				While(1)	5.68	5.75	5.77		56.80	57.50	57.70	

1. Guaranteed by characterization results, unless otherwise specified.

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Table 47. Current consumption in Run mode on SMPS, with different codes running from flash memory, Cache ON (2-way), Prefetch OFF(1)

Symbol	Parameter	Conditions			Typ			Unit	Typ			Unit
					25 °C				25 °C			
		-	Voltage scaling	Code	1.8 V	3.0 V	3.3 V		1.8 V	3.0 V	3.3 V	
$I_{DD(Run)}$	Supply current in Run mode	All peripherals disabled, SRAM1 and SRAM2 enabled	Range 2, $f_{HCLK1} = f_{HSI16}$ = 16 MHz	Reduced code	0.80	0.60	0.58	mA	49.93	37.57	35.95	µA/MHz
				Coremark®	0.81	0.61	0.58		50.63	38.13	36.25	
				SecureMark	0.83	0.62	0.6		51.88	38.75	37.50	
				Dhrystone 2.1	0.84	0.63	0.6		52.50	39.38	37.50	
				Fibonacci	0.77	0.58	0.58		48.13	36.25	36.25	
				While(1)	0.61	0.48	0.46		38.13	30.00	28.75	
			Range 1, $f_{HCLK1} = f_{HSE32}$ = 32 MHz	Reduced code	2.68	2.15	2.08		83.75	67.19	65.00	
				Coremark®	2.7	2.16	2.09		84.38	67.50	65.31	
				SecureMark	2.86	2.26	2.19		89.38	70.63	68.44	
				Dhrystone 2.1	2.85	2.26	2.18		89.06	70.63	68.13	
				Fibonacci	2.58	2.08	2.02		80.63	65.00	63.13	
				While(1)	2.06	1.73	1.7		64.38	54.06	53.13	
			Range 1, f_{HCLK1} = HSE32 + PLL at 100 MHz	Reduced code	6.73	4.88	4.63		67.27	48.80	46.25	
				Coremark®	6.80	4.93	4.67		68.02	49.30	46.72	
				SecureMark	7.2	5.19	4.91		72.00	51.90	49.10	
				Dhrystone 2.1	7.27	5.23	4.95		72.70	52.30	49.50	
				Fibonacci	6.4	4.67	4.43		64.00	46.70	44.30	
				While(1)	4.77	3.59	3.43		47.70	35.90	34.30	

1. Guaranteed by characterization results, unless otherwise specified.

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Table 48. Current consumption in Sleep modes, flash memory in power-down(1)(2)

Symbol	Parameter	Conditions				Typ			Unit
		-	-	Voltage scaling	f_{HCLK}	25 °C	55 °C	85 °C	
$I_{DD(Sleep)}$	Supply current in Sleep mode	$f_{HCLK1} = f_{HSI16}$ = 16 MHz	LDO	Range 2	16 MHz	0.44	0.51	0.68	mA
		$f_{HCLK1} = f_{HSE32}$ = 32 MHz		Range 1	32 MHz	1.34	1.49	1.81	
		f_{HCLK1} = HSE32 + PLL > 32 MHz			100 MHz	3.06	3.22	3.55	
		$f_{HCLK1} = f_{HSI16}$ = 16 MHz	SMPS	Range 2	16 MHz	0.25	0.28	0.35	
		$f_{HCLK1} = f_{HSE32}$ = 32 MHz		Range 1	32 MHz	1.07	1.17	1.35	
		f_{HCLK1} = HSE32 + PLL > 32 MHz			100 MHz	2	2.11	2.3	

1. Evaluated by characterization, not tested in production, unless otherwise specified.
2. All peripherals disabled.

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Table 49. Flash memory static power consumption(1)

Symbol	Parameter	Conditions	Typ			Unit
			25 °C	55 °C	85 °C	
I_{DD} (Flash)	Static consumption in normal mode	PD = 1 versus PD = 0	91.47	95.63	105.26	µA
I_{DD} (Flash_LPM)	Additional static consumption in normal versus low-power mode	LPM = 1 versus LPM = 0	51.49	52.38	53.85	

1. Evaluated by characterization, not tested in production, unless otherwise specified.

Table 50. Current consumption in Stop 0 mode(1)

Symbol	Parameter	Conditions			Typ			Unit
		-	-	V_{DD}	25 °C	55 °C	85 °C	
$I_{DD(Stop\ 0)}$	Supply current in Stop 0 mode, no retention	LDO	Range 2	1.8 V	52.56	87.12	180.79	µA
				2.4 V	52.92	87.68	180.98	
				3.0 V	53.55	88.61	182.45	
				3.3 V	54.35	90.20	185.82	
				3.6 V	56.52	95.08	199.54	
	Supply current in Stop 0 mode, all retention (SRAM1 448K + SRAM2 64K + PKA + OTG + ICACHE)			1.8 V	59.73	101.71	216.76	
				2.4 V	60.02	102.13	216.83	
				3.0 V	60.66	103.01	218.25	
				3.3 V	61.55	104.78	222.34	
				3.6 V	63.88	110.24	238.32	
$I_{DD(Stop\ 0)}$	Supply current in Stop 0 mode, SRAM2 retained	LDO	Range 2	1.8 V	53.58	89.57	187.01	µA
				2.4 V	53.95	90.01	186.70	
				3.0 V	54.55	90.91	188.76	
				3.3 V	55.33	92.31	191.51	
				3.6 V	57.17	96.32	202.09	
	Supply current in Stop 0 mode, ICACHE retained			1.8 V	52.67	87.47	181.74	
				2.4 V	53.06	87.95	181.50	
				3.0 V	53.68	88.78	183.20	
				3.3 V	54.36	90.19	186.04	
				3.6 V	56.07	93.76	195.24	

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Table 50. Current consumption in Stop 0 mode(1) (continued)

Symbol	Parameter	Conditions			Typ			Unit
		-	-	V_{DD}	25 °C	55 °C	85 °C	
$I_{DD(Stop\ 0)}$	Supply current in Stop 0 mode, no retention	SMPS	Range 2	1.8 V	18.50	39.49	99.22	µA
				2.4 V	15.71	32.16	78.61	
				3.0 V	14.31	28.12	67.27	
				3.3 V	14.13	27.12	63.82	
				3.6 V	14.51	27.32	63.45	
	Supply current in Stop 0 mode, all retention (SRAM1 448K + SRAM2 64K + PKA + OTG + ICACHE)			1.8 V	22.87	48.51	122.04	
				2.4 V	19.09	39.12	96.32	
				3.0 V	17.10	33.88	81.97	
				3.3 V	16.70	32.44	77.41	
				3.6 V	16.95	32.40	76.67	
$I_{DD(Stop\ 0)}$	Supply current in Stop 0 mode, SRAM2 retained	SMPS	Range 2	1.8 V	19.12	40.97	103.27	µA
				2.4 V	16.21	33.27	81.65	
				3.0 V	14.73	29.03	69.61	
				3.3 V	14.47	27.89	66.01	
				3.6 V	14.79	27.99	65.15	
	Supply current in Stop 0 mode, ICACHE retained			1.8 V	18.59	39.70	99.85	
				2.4 V	15.77	32.25	79.03	
				3.0 V	14.38	28.18	67.41	
				3.3 V	14.15	27.14	63.92	
				3.6 V	14.48	27.19	62.92	

1. Evaluated by characterization, not tested in production, unless otherwise specified.

Table 51. Current consumption in Stop 1 mode(1)

Symbol	Parameter	Conditions			Typ			Unit
		-	-	V_{DD}	25 °C	55 °C	85 °C	
$I_{DD(Stop\ 1)}$	Supply current in Stop 1 mode, no retention, ULPMEN = 1	LDO	Range 2	1.8 V	21.73	50.79	148.67	µA
				2.4 V	21.60	53.05	149.17	
				3.0 V	25.26	56.39	149.52	
				3.3 V	24.61	54.57	153.74	
				3.6 V	27.53	59.56	169.09	
	Supply current in Stop 1 mode, all retention (SRAM1 448K + SRAM2 64K + PKA + OTG + ICACHE), ULPMEN = 1			1.8 V	27.12	72.08	186.31	
				2.4 V	27.02	66.50	187.44	
				3.0 V	31.58	69.19	187.26	
				3.3 V	30.58	64.83	190.94	
				3.6 V	34.17	83.43	207.14	

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Table 51. Current consumption in Stop 1 mode(1) (continued)

Symbol	Parameter	Conditions			Typ			Unit
		-	-	V_{DD}	25 °C	55 °C	85 °C	
$I_{DD(Stop\ 1)}$	Supply current in Stop 1 mode, SRAM2 retained, ULPMEN = 1	LDO	Range 2	1.8 V	22.47	52.61	155.42	µA
				2.4 V	22.44	54.77	156.54	
				3.0 V	26.02	58.33	154.75	
				3.3 V	25.25	56.29	161.01	
				3.6 V	27.79	60.21	169.43	
	Supply current in Stop 1 mode, ICACHE retained, ULPMEN = 1			1.8 V	21.81	51.00	149.93	
				2.4 V	21.73	53.23	149.85	
				3.0 V	25.19	56.60	150.62	
				3.3 V	24.42	54.46	157.61	
				3.6 V	26.81	57.99	160.97	
$I_{DD(Stop\ 1)}$	Supply current in Stop 1 mode, no retention, ULPMEN = 1	SMPS	Range 2	1.8 V	14.66	35.49	95.59	µA
				2.4 V	11.49	27.76	74.84	
				3.0 V	9.70	23.40	62.85	
				3.3 V	9.28	22.19	59.31	
				3.6 V	9.36	22.06	58.23	
	Supply current in Stop 1 mode, all retention (SRAM1 448K + SRAM2 64K + PKA + OTG + ICACHE), ULPMEN = 1			1.8 V	19.05	44.58	118.90	
				2.4 V	14.89	34.73	92.93	
				3.0 V	12.53	29.23	77.92	
				3.3 V	11.90	27.62	73.27	
				3.6 V	11.83	27.17	71.64	
$I_{DD(Stop\ 1)}$	Supply current in Stop 1 mode, SRAM2 retained, ULPMEN = 1	SMPS	Range 2	1.8 V	15.28	37.00	99.57	µA
				2.4 V	12.00	28.86	77.88	
				3.0 V	10.13	24.32	65.41	
				3.3 V	9.67	23.05	61.69	
				3.6 V	9.72	22.83	60.27	
	Supply current in Stop 1 mode, ICACHE retained, ULPMEN = 1			1.8 V	14.72	35.73	96.07	
				2.4 V	11.59	27.87	75.11	
				3.0 V	9.78	23.52	63.13	
				3.3 V	9.33	22.29	59.53	
				3.6 V	9.38	22.04	58.17	

1. Evaluated by characterization, not tested in production, unless otherwise specified.

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Table 52. Current consumption in Stop 2 mode(1)

Symbol	Parameter	Conditions			Typ			Unit
		-	-	V_{DD}	25 °C	55 °C	85 °C	
$I_{DD(Stop\ 2)}$	Supply current in Stop 2 mode, no retention, ULPMEN = 1	LDO	Range 2	1.8 V	11.82	29.04	84.36	µA
				2.4 V	12.20	30.14	83.97	
				3.0 V	12.04	29.13	86.31	
				3.3 V	18.81	31.69	86.12	
				3.6 V	19.85	34.61	95.24	
	Supply current in Stop 2 mode, all retention (SRAM1 448K + SRAM2 64K + PKA + OTG + ICACHE), ULPMEN = 1			1.8 V	16.74	41.66	122.71	
				2.4 V	18.04	43.72	122.23	
				3.0 V	17.97	41.69	122.67	
				3.3 V	28.29	45.21	126.68	
				3.6 V	30.02	48.88	137.34	
$I_{DD(Stop\ 2)}$	Supply current in Stop 2 mode, SRAM2 retained, ULPMEN = 1	LDO	Range 2	1.8 V	12.06	30.77	88.19	µA
				2.4 V	12.99	32.30	88.94	
				3.0 V	12.96	31.22	94.36	
				3.3 V	19.76	34.28	91.81	
				3.6 V	20.93	36.15	99.79	
	Supply current in Stop 2 mode, ICACHE retained, ULPMEN = 1			1.8 V	11.95	29.37	83.93	
				2.4 V	12.23	30.64	87.08	
				3.0 V	12.18	29.38	86.93	
				3.3 V	18.44	31.79	87.29	
				3.6 V	19.52	33.91	91.42	
$I_{DD(Stop\ 2)}$	Supply current in Stop 2 mode, no retention, ULPMEN = 1	SMPS	Range 2	1.8 V	7.58	19.23	52.90	µA
				2.4 V	5.95	15.04	41.55	
				3.0 V	5.05	12.81	35.38	
				3.3 V	4.92	12.36	33.72	
				3.6 V	5.21	12.67	33.89	
	Supply current in Stop 2 mode, all retention (SRAM1 448K + SRAM2 64K + PKA + OTG + ICACHE), ULPMEN = 1			1.8 V	12.04	28.77	78.14	
				2.4 V	9.42	22.42	61.04	
				3.0 V	7.92	18.94	51.51	
				3.3 V	7.58	18.04	48.63	
				3.6 V	7.72	18.09	48.13	

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Table 52. Current consumption in Stop 2 mode(1) (continued)

Symbol	Parameter	Conditions			Typ			Unit
		-	-	V_{DD}	25 °C	55 °C	85 °C	
$I_{DD(Stop\ 2)}$	Supply current in Stop 2 mode, SRAM2 retained, ULPMEN = 1	SMPS	Range 2	1.8 V	8.24	20.81	57.36	µA
				2.4 V	6.46	16.26	44.93	
				3.0 V	5.48	13.83	38.07	
				3.3 V	5.30	13.28	36.28	
				3.6 V	5.58	13.52	36.09	
	Supply current in Stop 2 mode, ICACHE retained, ULPMEN = 1			1.8 V	7.67	19.46	53.60	
				2.4 V	6.03	15.24	42.00	
				3.0 V	5.12	12.97	35.74	
				3.3 V	4.98	12.46	34.01	
				3.6 V	5.26	12.74	33.94	

1. Evaluated by characterization, not tested in production, unless otherwise specified.

Table 53. Current consumption in Standby retention mode(1)

Symbol	Parameter	Conditions			Typ	-	-	Unit
		-	-	VDD	25 °C	55 °C	85 °C	
$I_{DD(Standby\ with\ retention)}$	Supply current in Standby retention mode, all retention (SRAM1 448K + SRAM2 64K + Radio), ULPMEN = 1	LDO	-	1.8 V	7.91	15.30	43.40	µA
				2.4 V	9.14	15.70	43.70	
				3.0 V	8.88	17.00	46.70	
				3.3 V	14.20	18.40	39.40	
				3.6 V	15.40	21.20	41.40	
	Supply current in Standby retention mode, SRAM2 retained, ULPMEN = 1			1.8 V	4.84	4.79	12.00	
				2.4 V	4.13	4.94	12.10	
				3.0 V	2.63	5.44	13.00	
				3.3 V	2.53	6.19	14.40	
				3.6 V	2.30	7.45	16.00	

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Table 53. Current consumption in Standby retention mode(1) (continued)

Symbol	Parameter	Conditions			Typ	-	-	Unit
		-	-	VDD	25 °C	55 °C	85 °C	
$I_{DD(Standby with retention)}$	Supply current in Standby retention mode, Radio retained, ULPMEN = 1	LDO	-	1.8 V	1.37	2.86	7.51	µA
				2.4 V	1.49	2.97	7.64	
				3.0 V	1.60	3.33	8.38	
				3.3 V	1.37	3.85	9.31	
				3.6 V	3.15	5.03	10.30	
	Supply current in Standby retention mode, all retention (SRAM1 448K + SRAM2 64K + Radio), ULPMEN = 1	SMPS		1.8 V	5.13	10.30	26.30	µA
				2.4 V	4.03	8.17	20.70	
				3.0 V	3.45	7.07	17.70	
				3.3 V	3.42	6.98	17.10	
				3.6 V	3.81	7.58	16.70	
	Supply current in Standby retention mode, SRAM2 retained, ULPMEN = 1			1.8 V	1.32	2.96	8.17	
				2.4 V	1.09	2.44	6.72	
				3.0 V	1.01	2.30	6.27	
				3.3 V	1.15	2.52	6.51	
				3.6 V	1.64	3.25	7.18	
$I_{DD(Standby with retention)}$	Supply current in Standby retention mode, Radio retained, ULPMEN = 1	SMPS	-	1.8 V	0.78	1.77	4.99	µA
				2.4 V	0.67	1.52	4.29	
				3.0 V	0.67	1.54	4.28	
				3.3 V	0.83	1.79	4.67	
				3.6 V	1.33	2.56	5.52	

1. Evaluated by characterization, not tested in production, unless otherwise specified.

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Table 54. Current consumption in Standby mode(1)

Symbol	Parameter	Conditions		Typ			Unit
		-	VDD	25 °C	55 °C	85 °C	
$I_{DD(Standby)}$	Supply current in Standby mode, all peripherals disabled	ULPMEN = 1	1.8 V	0.12	0.37	1.43	µA
			2.4 V	0.15	0.42	1.54	
			3.0 V	0.22	0.60	1.99	
			3.3 V	0.39	0.93	2.60	
			3.6 V	0.87	1.76	3.76	
		ULPMEN = 0	1.8 V	1.24	1.49	2.53	
			2.4 V	1.58	1.86	2.93	
			3.0 V	1.97	2.36	3.67	
			3.3 V	2.30	2.85	4.43	
			3.6 V	2.95	3.85	5.71	
	Supply current in Standby mode, IWDG enabled	Clocked by LSI1, ULPMEN = 0	1.8 V	1.46	1.72	2.75	
			2.4 V	1.87	2.15	3.23	
			3.0 V	2.34	2.73	4.04	
			3.3 V	2.71	3.26	4.85	
			3.6 V	3.40	4.28	6.22	
		Clocked by LSI1/128, ULPMEN = 0	1.8 V	1.33	1.59	2.62	
			2.4 V	1.69	1.96	3.04	
			3.0 V	2.09	2.48	3.79	
			3.3 V	2.42	2.97	4.57	
			3.6 V	3.07	3.95	5.89	

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Table 54. Current consumption in Standby mode(1) (continued)

Symbol	Parameter	Conditions		Typ			Unit
		-	VDD	25 °C	55 °C	85 °C	
$I_{DD(Standby with RTC)}$	Supply current in Standby mode, no IWDG, RTC enabled	Clocked by LSI1, ULPMEN = 0	1.8 V	1.45	1.71	2.75	µA
			2.4 V	1.87	2.15	3.22	
			3.0 V	2.33	2.72	4.04	
			3.3 V	2.70	3.24	4.83	
			3.6 V	3.38	4.26	6.20	
		Clocked by LSI1/128, ULPMEN = 0	1.8 V	1.33	1.59	2.62	
			2.4 V	1.69	1.96	3.04	
			3.0 V	2.09	2.48	3.80	
			3.3 V	2.42	2.97	4.56	
			3.6 V	3.08	3.95	5.89	
		Clocked by LSE bypass 32.768 kHz, ULPMEN = 0	1.8 V	1.69	2.05	3.31	
			2.4 V	2.09	2.47	3.81	
			3.0 V	2.54	3.04	4.69	
			3.3 V	2.91	3.59	5.57	
			3.6 V	3.60	4.66	7.13	
		Clocked by LSE crystal 32.768 kHz in medium low-drive, ULPMEN = 0	1.8 V	1.74	2.06	3.40	
			2.4 V	2.14	2.48	3.47	
			3.0 V	2.60	3.06	4.29	
			3.3 V	2.99	3.61	5.10	
			3.6 V	3.73	4.66	6.56	

1. Evaluated by characterization, not tested in production, unless otherwise specified.

I/O system current consumption

The current consumption of the I/O system has two components: static and dynamic.

I/O static current consumption

All the I/Os used as inputs with pull-up or pull-down generate current consumption when the pin is externally held to the opposite level. The value of this current consumption can be simply computed by using the pull-up/pull-down resistors values given in *Section 5.3.17*.

For the output pins, any internal or external pull-up or pull-down and external load must also be considered to estimate the current consumption.

An additional current consumption is due to I/Os configured as inputs when an intermediate voltage level is applied externally. This is caused by the input Schmitt trigger circuits used to discriminate the input value. Unless this specific configuration is required by the application, this supply current consumption can be avoided by configuring these I/Os in analog mode. This is the case of ADC input pins, which must be configured as analog inputs.

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Caution: Any floating input pin can settle to an intermediate voltage level or switch inadvertently, as a result of external electromagnetic noise. To avoid current consumption related to floating pins, they must be configured in analog mode, or forced internally to a definite digital value. This can be done by using pull-up/down resistors, or by configuring the pins in output mode.

I/O dynamic current consumption

The I/Os used in application increase the consumption measured previously (see *Table 55*). When an I/O pin switches, it uses the current from the I/O supply voltage to supply the pin circuitry, and to charge/discharge the capacitive load (internal and external) connected to it:

$$I_{SW} = V_{DD} \times f_{SW} \times C$$

where:

- I_{SW} is the current sunk by a switching I/O to charge/discharge the capacitive load
- V_{DD} is the I/O supply voltage
- f_{SW} is the I/O switching frequency
- C is the total capacitance seen by the I/O pin: $C = C_{INT} + C_{EXT} + C_S$
  - C_{INT} is the I/O pin capacitance
  - C_{EXT} is any connected external device pin capacitance
  - C_S is the PCB board capacitance

The pin is configured in push-pull output mode, and is toggled by software at a fixed frequency.

On-chip peripheral current consumption

The power consumption of the digital part of the peripherals is given in *Table 55*, while that of the analog part (when applicable) is indicated in the related sections.

The MCU is put under the following conditions:

- All I/O pins are in analog mode
- The given value is calculated by measuring the difference of the current consumptions:
  - when the peripheral is clocked on
  - when the peripheral is clocked off
- The ambient operating temperature and supply voltage conditions summarized in *Table 30*

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Table 55. Peripheral typical dynamic current consumption(1)

Bus	Peripheral	Range 1 LDO	Range 2 LDO	Range 1 SMPS	Range 2 SMPS	Unit
AHB1	AHB1 bus	0.316	0.154	0.122	0.065	µA/MHz
	SRAM1	1.006	0.731	0.525	0.288	
	TSC	1.501	1.104	0.785	0.448	
	CRC	0.318	0.237	0.178	0.089	
	RAMCFG	0.223	0.161	0.102	0.053	
	GPDMA1	2.254	1.647	1.179	0.675	
	ICACHE	0.682	0.495	0.354	0.198	
	FLASH interface	1.981	1.464	1.038	0.585	
	GTZC1	0.572	0.424	0.293	0.159	
AHB2	AHB2 bus(2)	0.649	0.393	0.291	0.145	
	SRAM2	0.284	0.225	0.179	0.090	
	PKA	5.695	4.209	3.004	1.721	
	HSEM	0.074	0.075	0.063	0.026	
	SAES	63.216	47.362	33.551	19.185	
	RNG	1.439	1.091	0.781	0.448	
	HASH	1.353	1.006	0.749	0.408	
	AES	1.605	1.205	0.868	0.486	
	GPIOA	0.000	0.000	0.000	0.000	
	GPIOB	0.000	0.000	0.000	0.000	
	GPIOC	0.000	0.000	0.000	0.000	
	GPIOD	0.000	0.000	0.000	0.000	
	GPIOE	0.000	0.000	0.000	0.000	

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Table 55. Peripheral typical dynamic current consumption(1) (continued)

Bus	Peripheral	Range 1 LDO	Range 2 LDO	Range 1 SMPS	Range 2 SMPS	Unit
AHB2	GPIOG	0.000	0.000	0.000	0.000	µA/MHz
	GPIOH	0.000	0.000	0.000	0.000	
	USB	18.539	13.828	9.916	5.581	
AHB4	AHB4 bus	0.000	0.000	0.023	0.000	
	ADC4 kernel clock domain	1.790	1.333	0.941	0.530	
	ADC4 bus clock domain	3.380	2.447	1.737	0.989	
	PWR	0.040	0.020	0.030	0.010	
AHB5	AHB5 bus and peripherals(3)	0.085	0.053	0.050	0.018	
APB1	AHB to APB1(4)	0.054	0.000	0.024	0.000	
	TIM2	3.171	2.363	1.676	0.952	
	TIM3	2.670	1.994	1.418	0.803	
	TIM4	2.990	2.236	1.593	0.904	
	WWDG	0.255	0.208	0.149	0.079	
	USART2 kernel clock domain	3.142	2.320	1.657	0.957	
	USART2 bus clock domain	4.604	3.434	2.520	1.388	
	USART3 kernel clock domain	3.057	2.273	1.628	0.926	
	USART3 bus clock domain	4.498	3.347	2.381	1.354	
	I2C1 kernel clock domain	1.526	1.134	0.793	0.467	
	I2C1 bus clock domain	2.270	1.713	1.213	0.697	
	I2C2 kernel clock domain	1.612	1.208	0.859	0.474	
	I2C2 bus clock domain	2.360	1.767	1.255	0.721	
	I2C4 kernel clock domain	1.647	1.227	0.869	0.486	
	I2C4 bus clock domain	2.425	1.816	1.273	0.732	
	LPTIM2 kernel clock domain	2.898	2.171	1.539	0.881	
	LPTIM2 bus clock domain	3.896	2.899	2.056	1.172	
	SPI2 kernel clock domain	0.562	0.412	0.294	0.168	
	SPI2 bus clock domain	1.984	1.494	1.062	0.603	
APB2	AHB to APB2(4)	0.219	0.151	0.049	0.047	
	TIM1	4.717	3.472	2.575	1.411	
	SPI1 kernel clock domain	0.543	0.408	0.299	0.163	
	SPI1 bus clock domain	2.152	1.584	1.127	0.645	
	TIM17	1.775	1.301	0.921	0.528	

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Table 55. Peripheral typical dynamic current consumption(1) (continued)

Bus	Peripheral	Range 1 LDO	Range 2 LDO	Range 1 SMPS	Range 2 SMPS	Unit
APB2	TIM16	1.811	1.338	0.953	0.548	µA/MHz
	USART1 kernel clock domain	3.115	2.305	1.651	0.929	
	USART1 bus clock domain	4.639	3.420	2.526	1.390	
	SAI1 kernel clock domain	0.864	0.641	0.458	0.266	
	SAI1 bus clock domain	2.566	1.893	1.350	0.770	
APB7	AHB to APB7(4)	0.704	0.493	0.371	0.197	
	SYSCFG	0.394	0.295	0.194	0.106	
	SPI3 kernel clock domain	0.553	0.404	0.285	0.161	
	SPI3 bus clock domain	1.799	1.334	0.948	0.531	
	LPUART1 kernel clock domain	2.243	1.667	1.187	0.682	
	LPUART1 bus clock domain	3.426	2.529	1.811	1.020	
	I2C3 kernel clock domain	1.777	1.331	0.939	0.533	
	I2C3 bus clock domain	2.482	1.856	1.314	0.749	
	LPTIM1 kernel clock domain	2.930	2.190	1.553	0.890	
	LPTIM1 bus clock domain	3.945	2.915	2.080	1.181	
	COMP	0.217	0.154	0.115	0.058	
	RTC/TAMP	1.530	1.145	0.821	0.453	
	VREFBUF	0.097	0.079	0.067	0.027	

1. Evaluated by characterization, not tested in production, unless otherwise specified.
2. The AHB bus is automatically active when at least one peripheral is ON on the AHB or associated APB.
3. RADIO inactive.
4. The AHB to APB bridge is automatically active when at least one peripheral is ON on the APB.

5.3.9 Wake-up time from low-power modes and voltage scaling transition times

The times given in *Table 56* are the latency between the event and the execution of the first user instruction (FSTEN = 1 in PWR_CR3 if not mentioned differently).

The device goes in Low-power mode after the WFE (Wait For Event) instruction.

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Table 56. Low-power mode wake-up timings - LDO(1)

Symbol	Parameter	Conditions	Typ	Unit
$t_{WU(Stop\ 0)}$	Wake-up time from Stop 0 to Run mode in flash memory, SRAMs retained	FLASHFWU = 0	12.98	µs
	Wake-up time from Stop 0 to Run mode in SRAM2		13.36	
$t_{WU(Stop\ 1)}$	Wake-up time from Stop 1 to Run mode in flash memory, SRAMs retained		27.10	
	Wake-up time from Stop 1 to Run mode in SRAM2		27.66	
$t_{WU(Stop\ 2)}$	Wake-up time from Stop 2 to Run mode in flash memory, SRAMs retained		27.10	
	Wake-up time from Stop 2 to Run mode in SRAM2		27.66	
$t_{WU(Standby\ with\ retention)}$	Wake-up time from Standby retention to Run mode in flash memory		51.49	
	Wake-up time from Standby to Run mode in SRAM2		51.49	
$t_{WU(Standby)}$	Wake-up time from Standby to Run mode in flash memory	FSTEN = 1	104.59	
		FSTEN = 0	556.39	

1. Evaluated by characterization, not tested in production, unless otherwise specified.

Table 57. Low-power mode wake-up timings - SMPS(1)

Symbol	Parameter	Conditions	Typ	Unit
$t_{WU(Stop\ 0)}$	Wake-up time from Stop 0 to Run mode in flash memory, SRAMs retained	FLASHFWU = 0	12.92	µs
	Wake-up time from Stop 0 to Run mode in SRAM2		13.36	
$t_{WU(Stop\ 1)}$	Wake-up time from Stop 1 to Run mode in flash memory, SRAMs retained		20.86	
	Wake-up time from Stop 1 to Run mode in SRAM2		21.24	
$t_{WU(Stop\ 2)}$	Wake-up time from Stop 2 to Run mode in flash memory, SRAMs retained		20.86	
	Wake-up time from Stop 2 to Run mode in SRAM2		21.24	
$t_{WU(Standby\ with\ retention)}$	Wake-up time from Standby retention to Run mode in flash memory		45.19	
	Wake-up time from Standby to Run mode in SRAM2		46.19	
$t_{WU(Standby)}$	Wake-up time from Standby to Run mode in flash memory	FSTEN = 1	104.59	
		FSTEN = 0	556.39	

1. Guaranteed by characterization results, unless otherwise specified.

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Table 58. Regulator modes transition times(1)

Symbol	Parameter	Conditions	Typ	Unit
t_{LDO}	SMPS to LDO transition time	Range 2	21.5	µs
		Range 1	17.2	
t_{SMPS}	LDO to SMPS transition time	Range 2	21.1	
		Range 1	20.2	
t_{VOST}(2)	Range 2 to range 1	LDO	47.3	
		SMPS	53.9	
	Range 1 to range 2(3)	LDO	39	
		SMPS	39.8	

1. Evaluated by characterization, not tested in production, unless otherwise specified.
2. Time for ACTVOSRDY in PWR_SVMSR to indicate selected new VOS range.
3. VOSRDY remains at 1 on a transition from range 1 to range 2.

Table 59. Wake-up time using USART/LPUART(1)

Symbol	Parameter	Typ	Max	Unit
,$t_{WUUSART}$ $t_{WULPUART}$	Wake-up time needed to calculate the maximum USART/LPUART baudrate needed to wake up from Stop mode when USART/LPUART kernel clock source is HSI16	-	$t_{su(HSI16)}$ max	µs

1. Specified by design, not tested in production.

5.3.10 External clock source characteristics

High-speed external clock

The high-speed external (HSE32) clock can be supplied with a 32 MHz crystal or a clock source.

The devices include internal programmable capacitances that can be used to trim the crystal frequency, to compensate the PCB parasitic one.

Table 60. HSE32 crystal requirements(1)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{HSE}	Oscillator frequency(2)	-	-	32	-	MHz
f_{TOL}	Frequency tolerance(3) includes initial accuracy, stability over temperature, aging, and frequency pulling due to incorrect load capacitance	Bluetooth Low Energy	-50	-	50	ppm
		IEEE802.15.4	-40	-	40	
C_L	Load capacitance	-	8	-	18	pF
C_O	Shunt capacitance	-	-	-	4	
ESR	Equivalent series resistance	-	60	-	150	Ω
C_{bank}	Capacitor bank range	-	6.6	-	23.6	pF

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Table 60. HSE32 crystal requirements(1) (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$C_{bank-step}$	Capacitor bank step size	-	215	270	325	fF
t_{STAB}	Oscillator stabilization time	-	-	100	160	µs
$I_{DDRF(HSE32)}$	Current consumption	-	-	205	-	µA

1. Specified by design, not tested in production.
2. 32 MHz XTAL is specified for two specific references: NX2016SA and NX1612SA.
3. After capacitor bank trimming.

Table 61. HSE32 clock source requirements(1)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{HSE32}	External clock source frequency(2)	-	-	32	-	MHz
f_{TOL}	Frequency tolerance includes initial accuracy, stability over temperature, and aging	Bluetooth Low Energy	-50	-	50	ppm
		IEEE802.15.4	-40	-	40	
V_{HSE32}	Clock input voltage limits	Input level	0	-	0.9	V
		Amplitude(3)	200	-	900	mV_{PP}
$DuCy_{HSE32}$	Duty cycle	-	45	-	55	%
$\varphi_{n(HSE32)}$	Phase noise for 32 MHz	Offset = 10 kHz	-	-	-127	dBc/Hz
		Offset = 100 kHz	-	-	-135	
		Offset = 1 MHz	-	-	-138	

1. Specified by design, not tested in production.
2. $f_{HSE} = 1/t_{HSE}$.
3. AC coupling is supported (470 pF to 100 nF capacitor).

Note: For information about oscillator trimming, refer to AN5042 "Precise HSE frequency and startup time tuning for STM32 wireless MCUs", available on www.st.com.

Low-speed external clock

The low-speed external (LSE) clock can be supplied with a crystal or a clock source. The information provided in this section is based on design simulation results, obtained with the typical external components specified in *Table 62*. In the application, the crystal and the load capacitors must be placed as close as possible to the oscillator pins, to minimize output distortion and startup stabilization time. Refer to the crystal resonator manufacturer for more details on the resonator characteristics (frequency, package, accuracy).

Table 62. LSE oscillator characteristics(1)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{LSE}	Oscillator frequency(2)	-	-	32.000 or 32.768	-	kHz

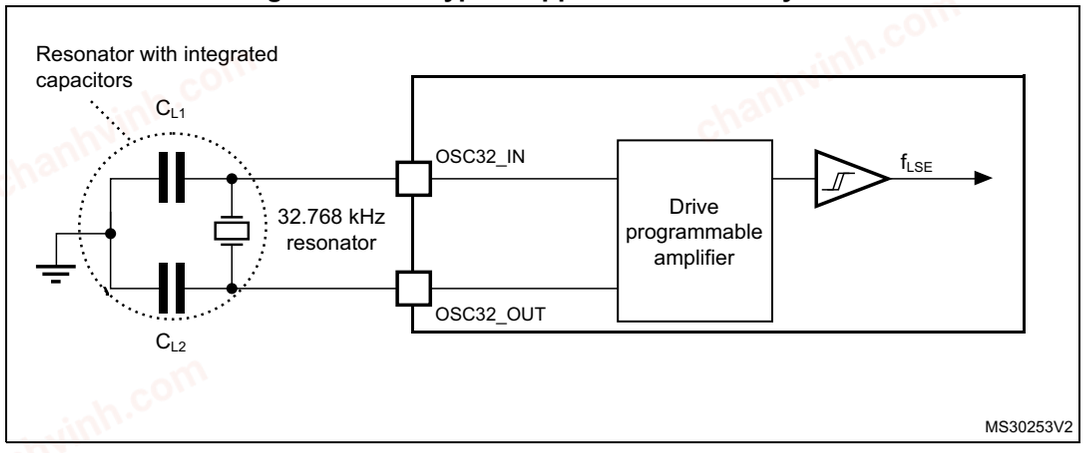
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Table 62. LSE oscillator characteristics(1) (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{TOL}	Frequency tolerance includes initial accuracy, stability over temperature, aging and frequency pulling due to incorrect load capacitance	Bluetooth Low Energy	-500	-	500	ppm
		Thread CSL	-255	-	255	
$I_{DD(LSE)}$	LSE current consumption	LSEDRV = medium-low drive capability	-	450	-	nA
		LSEDRV = medium-high drive capability	-	590	-	
		LSEDRV = high drive capability	-	700	-	
$Gm_{critmax}$	Maximum critical crystal Gm	LSEDRV = medium-low drive capability	-	-	0.75	µA/V
		LSEDRV = medium-high drive capability	-	-	1.70	
		LSEDRV = high drive capability	-	-	2.70	
C_{S_PARA}	Internal stray parasitic capacitance(3)	-	-	3	-	pF
$t_{SU(LSE)}$	Startup time(4)	V_{DD} is stabilized	-	2	-	s

1. Specified by design, not tested in production.
2. For information on selecting the crystal, refer to AN2867 '*Oscillator design guide for STM8AF/AL/S, STM32 MCUs and MPUs*".
3. CS_PARA is the equivalent capacitance seen by the crystal due to OSC32_IN and OSC32_OUT internal parasitic capacitances.
4. Time measured from when the LSE is enabled by software, until a stable LSE oscillation is reached. This value is measured for a standard crystal, and can vary significantly with the crystal used.

Figure 23. LSE typical application with a crystal



Note: No external resistors are required between OSC32_IN and OSC32_OUT, and it is forbidden to add one.

In bypass mode the LSE oscillator is switched off, and the input pin OSC32_IN is a standard GPIO.

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Table 63. LSE external clock bypass mode characteristics(1)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{LSE_ext}	External clock source frequency(2)	-	32.000	32.768	-	kHz
f_{TOL}	Frequency tolerance includes initial accuracy and stability over temperature	Bluetooth Low Energy	-500	-	500	ppm
		Thread CSL	-225	-	225	
V_{IL}	OSC32_IN input low level voltage	-	-	-	0.3 x V_{DD}	V
V_{IH}	OSC32_IN input high level voltage	-	0.7 x V_{DD}	-	-	V
$t_{w(LSEH)}$ $t_{w(LSEL)}$	OSC32_IN input high or low time for square signal	-	10	-	-	µs

1. Specified by design, not tested in production.
2. $f_{LSE} = 1/t_{LSE}$.

5.3.11 Internal clock source characteristics

The parameters given in the following tables are derived under ambient operating temperature and supply voltage conditions summarized in *Table 30*.

High-speed internal (HSI16) RC oscillator

Table 64. HSI16 oscillator characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{HSI16}	Frequency after factory calibration	V_{DD} = 3.0 V, T_J = 30 °C calibrated during production	15.92	16	16.08	MHz
		1.71 V ≤ V_{DD} ≤ 3.6 V, T_J = -10 to 100 °C(1)	15.84	16	16.16	
		1.71 V ≤ V_{DD} ≤ 3.6 V, T_J = -40 to 130 °C (1)	15.65	16	16.35	
TRIM(2)	User trimming step	-	18	29	40	kHz
$DuCy_{HSI16}$(2)	Duty cycle	-	45	-	55	%
$t_{su(HSI16)}$(2)	Startup time	-	-	2.5	3.6	µs
$t_{stab(HSI16)}$(2)	Stabilization time	-	-	4	6	
$I_{DD(HSI16)}$(2)	Power consumption	-	-	150	210	µA

1. Evaluated by characterization, not tested in production, unless otherwise specified. It does not take into account package and soldering effects.
2. Specified by design, not tested in production.

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Low-speed internal (LSI) RC oscillator

Table 65. LSI1 oscillator characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{LSI1}	Frequency	V_{DD} = 3.0 V, T_J = 30 °C, LSIPREDIV = 1	0.245	0.25	0.255	kHz
		V_{DD} = 3.0 V, T_J = 30 °C, LSIPREDIV = 0	31.4	32.0	32.6	
		1.71 V ≤ V_{DD} ≤ 3.6 V, T_J = -40 to 85 °C, LSIPREDIV = 0 (1)	30.4	32.0	33.6	
$DuCy_{LSI1}$	Duty cycle	LSIPREDIV = 1	-	50	-	%
$t_{SU(LSI1)}$(2)	Startup time	-	-	230	260	µs
$t_{STAB(LSI1)}$(2)	Stabilization time	5% of final frequency	-	230	260	
$I_{DD(LSI1)}$(2)	Power consumption	LSIPREDIV = 0	-	140	255	nA
		LSIPREDIV = 1	-	130	240	

1. Evaluated by characterization, not tested in production, unless otherwise specified.
2. Specified by design, not tested in production.

Table 66. LSI2 oscillator characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{LSI2}	Frequency	-	24	32	48	kHz
$t_{SU(LSI2)}$(1)	Startup time	-	550	-	750	µs
$t_{STAB(LSI2)}$(1)	Stabilization time	5% of final frequency	-	650	1100	
Δ_{TEMP}(2)	Stability over temperature	-	-200	-	200	ppm/ °C
$I_{DD(LSI2)}$(2)	Power consumption	-	-	1	2	µA

1. Specified by design, not tested in production.
2. Evaluated by characterization, not tested in production, unless otherwise specified.

5.3.12 PLL characteristics

The parameters given in *Table 67* are derived from tests performed at ambient temperature and under the supply voltage conditions summarized in *Table 30*.

Table 67. PLL characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{PLL_IN}(1)	PLL input clock	-	4	-	16	MHz
$DuCy_{PLL_IN}$(1)	PLL input clock duty cycle	-	10	-	90	%
f_{PLL_OUT}(1)	PLL output clock P, Q, and R	-	1	-	100	MHz
$DuCy_{PLL_OUT}$(1)	PLL output clock duty cycle	Division 1	40	-	60	%
f_{VCO_OUT}(1)	PLL VCO output	-	128	-	544	MHz
t_{LOCK}(2)	PLL lock time(3)	Integer mode	-	25	54	µs
		Fractional mode	-	40	65	

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Table 67. PLL characteristics (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Jitter(1)	RMS cycle-to-cycle jitter	Integer mode, VCO = 544 MHz	-	±20	-	ps
		Fractional mode, VCO = 544 MHz	-	±70	-	
	RMS period jitter	Integer mode, VCO = 544 MHz	-	±35	-	
		Fractional mode, VCO = 544 MHz	-	±45	-	
	Long-term jitter(4) f_{PLL_IN} = 8 MHz	Integer mode, VCO = 544 MHz	-	±160	-	
		Fractional mode, VCO = 544 MHz	-	±170	-	
$I_{DD(PLL)}$(1)	PLL power consumption on V_{DD} with LDO	VCO freq = 100 MHz	-	370	-	µA
		VCO freq = 200 MHz	-	460	-	
		VCO freq = 336 MHz	-	710	-	
		VCO freq = 544 MHz	-	1100	-	
	PLL power consumption on V_{DD} with SMPS.	VCO freq = 100 MHz, 1 clock output	-	260	-	µA
		VCO freq = 100 MHz, 3 clock outputs	-	270	-	
		VCO freq = 200 MHz, 1 clock output	-	320	-	
		VCO freq = 336 MHz, 1 clock output	-	470	-	
		VCO freq = 544 MHz, 1 clock output	-	730	-	

1. Specified by design, not tested in production.
2. Evaluated by characterization, not tested in production, unless otherwise specified.
3. Lock time is the duration until PLL1RDY flag (2% of final frequency).
4. Measured on 5000 cycles.

5.3.13 Flash memory characteristics

Table 68. Flash memory characteristics

Symbol	Parameter	Conditions	Typ	Max(1)	Unit
t_{prog}(2)	128-bit programming time	Normal mode	118	118	µs
		Burst mode	48	48	
t_{prog_page}(2)	One 8-Kbyte page programming time	f_{AHB} = 100 MHz, normal mode	62	-	ms
		f_{AHB} = 100 MHz, burst mode	24.9	-	
t_{prog_flash}(2)	1-Mbyte programming time	f_{AHB} = 100 MHz, normal mode	7930	-	
		f_{AHB} = 100 MHz, burst mode	3180	-	
t_{ERASE}(2)	One 8-Kbyte page erase time	10 k endurance cycles	1.5	2.4	
		100 k endurance cycles(3)	1.7	3.4	
t_{ME}(2)	Mass erase time (1-Mbyte, one bank)	10 k endurance cycles	195	308	
	Mass erase time (2-Mbyte, two banks)		390	616	

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Table 68. Flash memory characteristics (continued)

Symbol	Parameter	Conditions	Typ	Max(1)	Unit
I_{DD}(4)	Average consumption from V_{DD}	Write mode	2.1	-	mA
		Erase mode	1.3	-	
	Maximum current (peak) from V_{DD}	Write mode	2.6	-	
		Erase mode	3.0	-	

1. Evaluated by characterization after cycling, not tested in production.
2. Specified by design, not tested in production, unless otherwise specified.
3. Erase time applies to all pages in user area in flash main memory (only 32 pages can be cycled more than 10 k times)
4. Evaluated by characterization, not tested in production, unless otherwise specified.

Table 69. Flash memory endurance and data retention(1)

Symbol	Parameter	Conditions		Min	Unit
N_{END}	Endurance	Whole user flash	T_A = –40 to 105 °C	10	kcycles
		Limited to 32 pages per bank		100	
t_{RET}	Data retention(2)	Whole bank	T_A = 85 °C after 1 kcycles	30	
			T_A = 105 °C after 1 kcycles	15	
			T_A = 55 °C after 10 kcycles	30	
			T_A = 85 °C after 10 kcycles	15	
			T_A = 105 °C after 10 kcycles	10	
		Limited to 32 pages per bank	T_A = 55 °C after 100 kcycles	30	
			T_A = 85 °C after 100 kcycles	15	
			T_A = 105 °C after 100 kcycles	10	

1. Evaluated by characterization, not tested in production, unless otherwise specified.
2. Cycling performed over the whole temperature range.

5.3.14 EMC characteristics

Susceptibility tests are performed on a sample basis during device characterization.

Functional EMS (electromagnetic susceptibility)

While a simple application is executed on the device (toggling two LEDs through I/O ports), the device is stressed by two electromagnetic events until a failure occurs. The failure is indicated by the LEDs as follows:

- ESD (electrostatic discharge), positive and negative: applied to all device pins until a functional disturbance occurs. This test is compliant with the IEC 61000-4-2 standard.
- FTB (fast transient voltage burst), positive and negative: applied to V_{DD} and V_{SS} pins through a 100 pF capacitor, until a functional disturbance occurs. This test is compliant with the IEC 61000-4-4 standard.

A device reset allows normal operations to be resumed.

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The test results are given in *Table 70*. They are based on the EMS levels and classes defined in AN1709 "*EMC design guide for STM8, STM32 and legacy MCUs*".

Table 70. EMS characteristics(1)

Symbol	Parameter	Conditions	Level/Class
V_{FESD}	Voltage limits to apply on any I/O pin to induce a functional disturbance	V_{DD} = 3.3 V, T_A = +25 °C, f_{HCLK1} = 100 MHz, UFQFPN48 conforming to IEC 61000-4-2	3B
V_{EFTB}	Fast transient voltage burst limits to apply through 100 pF on V_{DD} and V_{SS} pins to induce a functional disturbance	V_{DD} = 3.3 V, T_A = +25 °C, f_{HCLK1} = 100 MHz, UFQFPN48 conforming to IEC 61000-4-4	5A

1. Evaluated by characterization, not tested in production, unless otherwise specified.

Designing hardened software to avoid noise problems

EMC characterization and optimization are performed at component level with a typical application environment and simplified MCU software.

Good EMC performance is highly dependent on the user application, and the software in particular. Therefore, it is recommended that the user applies EMC software optimization and prequalification tests in relation with the requested EMC level.

Software recommendations

The software flow must include the management of runaway conditions, such as:

- Corrupted program counter
- Unexpected reset
- Critical data corruption (control registers)

Prequalification trials

Most of the common failures (unexpected reset and program counter corruption) can be reproduced by manually forcing a low state on the NRST pin or on the oscillator pins for 1 second.

To complete these trials, ESD stress can be applied directly on the device, over the range of specified values. When an unexpected behavior is detected, the software can be hardened to prevent the occurrence of unrecoverable errors. See AN1015 "*Software techniques for improving microcontrollers EMC performance*" for more details.

Electromagnetic interference (EMI)

The electromagnetic field emitted by the device is monitored while a simple application is executed (toggling two LEDs through the I/O ports). This emission test is compliant with the IEC 61967-2 standard, which specifies the test board and the pin loading.

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Table 71. EMI characteristics for f_{HSE} = 32 MHz and f_{HCLK} = 100 MHz(1)

Symbol	Parameter	Conditions	Monitored frequency band	Value	Unit
S_{EMI}	Peak level(2)	V_{DD} = 3.6 V, T_A = 25 °C, UFQFPN48 package compliant with IEC 61967-2	0.1 MHz to 30 MHz	-	dBµV
			30 MHz to 130 MHz	-	
			130 MHz to 1 GHz	-	
			1 GHz to 2 GHz	-	
	Level(3)		EMI level	-	-

1. Evaluated by characterization, not tested in production.
2. Refer to AN1709, “EMI radiated test” section.
3. Refer to AN1709, “EMI level classification” section.

5.3.15 Electrical sensitivity characteristics

Based on three different tests (ESD, latch-up) using specific measurement methods, the device is stressed in order to determine its performance in terms of electrical sensitivity.

Electrostatic discharge (ESD)

Electrostatic discharges (a positive then a negative pulse separated by 1 second) are applied to the pins of each sample according to each pin combination. The sample size depends on the number of supply pins in the device (3 parts × (n+1) supply pins). This test conforms to the ANSI/JEDEC standard.

Table 72. ESD absolute maximum ratings(1)

Symbol	Ratings	Conditions	Package	Class	Max	Unit
$V_{ESD(HBM)}$	Electrostatic discharge voltage (human body model)	T_A = 25 °C, conforming to ANSI/ESDA/JEDEC JS-001	All	2	2000	V
$V_{ESD(CDM)}$	Electrostatic discharge voltage (charge device model)	T_A = 25 °C, conforming to ANSI/ESDA/JEDEC JS-002	UFQFPN48	C2a	500	
			VFQFPN68			
			Thin WLCSP88	C1	250	
			UFBGA121	-	-	

1. Evaluated by characterization, not tested in production, unless otherwise specified.

Static latch-up

The following complementary static tests are required on three parts to assess the latch-up performance:

- a supply overvoltage is applied to each power supply pin
- a current injection is applied to each input, output and configurable I/O pin.

These tests are compliant with EIA/JESD 78A IC latch-up standard.

Table 73. Electrical sensitivity(1)

Symbol	Parameter	Conditions	Class
LU	Static latch-up class	T_J = 130 °C conforming to JESD78E	2

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1. Evaluated by characterization, not tested in production, unless otherwise specified.

5.3.16 I/O current injection characteristics

As a general rule, current injection to the I/O pins, due to external voltage below V_{SS} or above V_{DD} (for standard, 3.3 V-capable I/O pins) should be avoided during normal product operation. However, in order to give an indication of the robustness of the microcontroller if abnormal injection accidentally happens, some susceptibility tests are performed on a sample basis during device characterization.

Functional susceptibility to I/O current injection

While a simple application is executed, the device is stressed by injecting current into the I/O pins programmed in floating input mode. While current is injected into the I/O pin, one at a time, the device is checked for functional failures.

The failure is indicated by an out-of-range parameter, such as an ADC error above a certain limit (higher than 5 LSB ET), out of conventional limits of induced leakage current on adjacent pins (out of the -5 µA/0 µA range) or other functional failure (for example reset occurrence or oscillator frequency deviation).

The characterization results are given in *Table 74*. The negative/positive induced leakage current is caused by the negative/positive injection.

Table 74. I/O current injection susceptibility(1)

Symbol	Description	Functional susceptibility		Unit
		Negative injection	Positive injection	
I_{INJ}	Injected current on all pins	5	N/A	mA

1. Evaluated by characterization, not tested in production, unless otherwise specified.

5.3.17 I/O port characteristics

General input/output characteristics

The parameters given in *Table 75* are derived from tests performed at ambient temperature and under the supply voltage conditions summarized in *Table 30*. All I/Os are designed as CMOS- and TTL-compliant.

Note: For information on I/O configuration, refer to AN4899 “STM32 GPIO configuration for hardware settings and low-power consumption”.

Table 75. I/O static characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{IL}	I/O input low level voltage	1.58 V ≤ V_{DD} ≤ 3.6 V, 1.08 V ≤ V_{DDIO2} ≤ 3.6 V	-	-	0.3 x V_{DD}	V
V_{IH}	I/O input high level voltage		0.7 x V_{DD}	-	-	
V_{hys}(1)	Input hysteresis	-	-	250	-	mV

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Table 75. I/O static characteristics (continued)

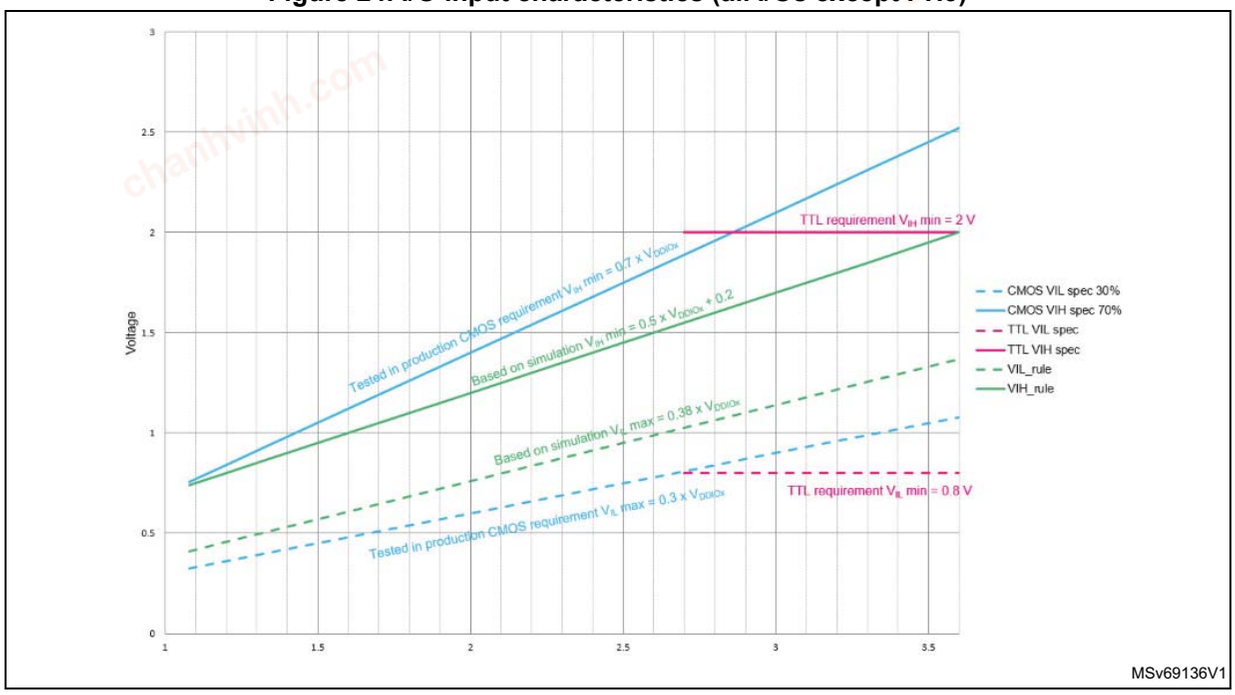
Symbol	Parameter		Conditions	Min	Typ	Max	Unit
I_{lkg}(1)	I/O input leakage current(2)(3)	All I/Os except FT_u	$V_{IN} \le Max(V_{DDx})$	-	-	150	nA
			$Max(V_{DDx}) < V_{IN} \le Max(V_{DDx}) + 1\ V$	-	-	2000	
			$Max(V_{DDx}) + 1\ V < V_{IN} \le 5.5\ V$(3)	-	-	500	
		FT_u I/Os	$V_{IN} \le Max(V_{DDx})$	-	-	200	
			$Max(V_{DDx}) < V_{IN} \le Max(V_{DDx}) + 1\ V$	-	-	2500	
			$Max(V_{DDx}) + 1\ V < V_{IN} \le 5.5\ V$(3)	-	-	500	
R_{PU}	Weak pull-up equivalent resistor(4)		-	30	40	50	kΩ
R_{PD}	Weak pull-down equivalent resistor(4)		-	30	40	50	
C_{IO}	I/O pin capacitance		-	-	5	-	pF

1. Specified by design, not tested in production.
2. This parameter represents the pad leakage of the I/O itself. The total product pad leakage is provided by the following formula: $I_{Total_Ileak_max}$ = 10 µA + [number of I/Os where V_{IN} is applied on the pad] x I_{lkg} max.
3. To sustain a voltage higher than min (V_{DD}, V_{DDIO2}, V_{DDUSB}, V_{DDA}) + 0.3 V, the internal pull-up and pull-down resistors must be disabled.
4. The pull-up and pull-down resistors are designed with a true resistance in series with a switchable PMOS/NMOS. This PMOS/NMOS contribution to the series resistance is minimal (~10%).

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All I/Os are CMOS- and TTL-compliant (no software configuration required). Their characteristics cover more than the strict CMOS-technology or TTL parameters. The coverage of these requirements is shown in *Figure 24*.

Figure 24. I/O input characteristics (all I/Os except PH3)



Output driving current

The I/Os can sink or source up to ±8 mA, up to ±20 mA with a relaxed V_{OL} / V_{OH}.

In the user application, the number of I/O pins that can drive current must be limited to respect the absolute maximum rating specified in *Section 5.2*.

- The sum of the currents sourced by all the I/Os on V_{DD}, plus the maximum consumption of the MCU sourced on V_{DD}, cannot exceed the absolute maximum rating ΣI_{VDD} (see *Table 27*).
- The sum of the currents sunk by all the I/Os on V_{SS}, plus the maximum consumption of the MCU sunk on V_{SS}, cannot exceed the absolute maximum rating ΣI_{VSS} (see *Table 27*).

Output voltage levels

Unless otherwise specified, the parameters given in *Table 76* are at ambient temperature and under the supply voltage conditions summarized in *Table 30*. All I/Os are CMOS- and TTL-compliant.

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Table 76. Output voltage characteristics(1)

Symbol	Parameter	Conditions	Min	Max	Unit
V_{OL}	Output low level voltage	$\|I_{IO}\|$ = 8 mA, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	0.4	V
V_{OH}	Output high level voltage		V_{DD} - 0.4	-	
V_{OL}(2)	Output low level voltage	$\|I_{IO}\|$ = 20 mA, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	1.3	
V_{OH}(2)	Output high level voltage		V_{DD} - 1.3	-	
V_{OL}(2)	Output low level voltage	$\|I_{IO}\|$ = 4 mA, 1.58 V ≤ V_{DD} ≤ 3.6 V	-	0.4	
V_{OH}(2)	Output high level voltage		V_{DD} - 0.4	-	
V_{OL}(2)	Output low level voltage	$\|I_{IO}\|$ = 1 mA, 1.08 V ≤ V_{DDIO2} ≤ 3.6 V	-	0.4	
V_{OH}(2)	Output high level voltage		V_{DDIO2} - 0.4	-	
V_{OLFM+}(2)	Output low level voltage for an I/O pin in Fm+ mode	$\|I_{IO}\|$ = 20 mA, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	0.4	
		$\|I_{IO}\|$ = 10 mA, 1.58 V ≤ V_{DD} ≤ 3.6 V	-	0.4	
		$\|I_{IO}\|$ = 2 mA, 1.08 V ≤ V_{DDIO2} ≤ 3.6 V	-	0.4	

1. The I_{IO} current sourced or sunk by the device must always respect the absolute maximum rating specified in *Table 26*, and the sum of the currents sourced or sunk by all the I/Os (I/O ports and control pins) must always respect the absolute maximum ratings $\Sigma I_{(PIN)}$.
2. Specified by design, not tested in production.

Output AC characteristics

The definition of output AC characteristics is given in *Figure 25*, values in *Table 77* and *Table 78*. Unless otherwise specified, the parameters in these tables are at ambient temperature and under the supply voltage conditions summarized in *Table 30*.

Table 77. Output AC characteristics, HSLV off(1)(2)

Speed(3)	Symbol	Parameter	Conditions	Min	Max	Unit
00	Fmax	Maximum frequency	C_L = 50 pF, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	12.5	MHz
			C_L = 50 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	5	
			C_L = 50 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	1	
			C_L = 10 pF, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	12.5	
			C_L = 10 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	5	
			C_L = 10 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	1	
	t_r/t_f	Output rise and fall time	C_L = 50 pF, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	17	ns
			C_L = 50 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	33	
			C_L = 50 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	85	
			C_L = 10 pF, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	12.5	
			C_L = 10 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	25	
			C_L = 10 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	50	

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Table 77. Output AC characteristics, HSLV off(1)(2) (continued)

Speed(3)	Symbol	Parameter	Conditions	Min	Max	Unit
01	Fmax	Maximum frequency	C_L = 30 pF, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	55	MHz
			C_L = 30 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	12.5	
			C_L = 30 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	2.5	
			C_L = 10 pF, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	55	
			C_L = 10 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	12.5	
			C_L = 30 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	2.5	
	t_r/t_f	Output rise and fall time	C_L = 30 pF, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	5.8	ns
			C_L = 30 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	10	
			C_L = 30 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	18	
			C_L = 10 pF, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	4.2	
			C_L = 10 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	7.5	
			C_L = 10 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	12	
10(4)	Fmax	Maximum frequency	C_L = 30 pF, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	100	MHz
			C_L = 30 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	33	
			C_L = 30 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	5	
			C_L = 10 pF, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	100	
			C_L = 10 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	40	
			C_L = 10 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	5	
	t_r/t_f	Output rise and fall time	C_L = 30 pF, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	3.3	ns
			C_L = 30 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	6.0	
			C_L = 30 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	13.3	
			C_L = 10 pF, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	2.0	
			C_L = 10 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	4.1	
			C_L = 10 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	9.2	
Fm+	Fmax	Maximum frequency	C_L = 550 pF, 1.08 V ≤ V_{DD} ≤ 3.6 V	-	1	MHz
	t_f	Output fall time(5)	C_L = 550 pF, 1.58 V ≤ V_{DD} ≤ 3.6 V	-	100	ns
			C_L = 550 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	200	
			C_L = 100 pF, 1.58 V ≤ V_{DD} < 3.6 V	-	50	
			C_L = 100 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	80	

1. Specified by design, not tested in production.
2. PB15 and PH3 output and input frequencies must not exceed 16 kHz, PC14 and PC15 output and input frequencies must not exceed 250 kHz, for these I/Os OSPEED must be kept at low speed.
3. The I/O speed is configured using the OSPEED bits, Fm+ is configured in SYSCFG. Refer to the product reference manual for the description.
4. I/O compensation system enabled.
5. The fall time is defined between 70% and 30% of the output waveform, according to the I^2C specification.

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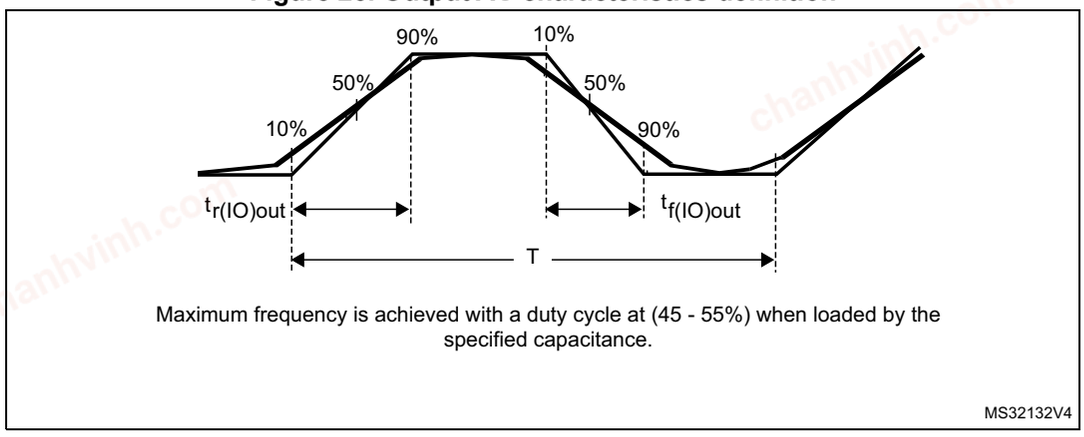
Table 78. Output AC characteristics, HSLV on(1)(2)

Speed(3)	Symbol	Parameter	Conditions	Min	Max	Unit
00	Fmax	Maximum frequency	C_L = 50 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	10	MHz
			C_L = 50 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	4	
			C_L = 10 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	15	
			C_L = 10 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	4	
	t_r/t_f	Output rise and fall time	C_L = 50 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	18	ns
			C_L = 50 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	32	
			C_L = 10 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	12	
			C_L = 10 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	21	
01	Fmax	Maximum frequency	C_L = 30 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	50	MHz
			C_L = 30 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	10	
			C_L = 10 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	67	
			C_L = 30 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	10	
	t_r/t_f	Output rise and fall time	C_L = 30 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	5.3	ns
			C_L = 30 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	10.6	
			C_L = 10 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	3.1	
			C_L = 10 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	5.6	
10(4)	Fmax	Maximum frequency	C_L = 30 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	75	MHz
			C_L = 30 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	15	
			C_L = 10 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	100	
			C_L = 10 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	15	
	t_r/t_f	Output rise and fall time	C_L = 30 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	4.4	ns
			C_L = 30 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	9.6	
			C_L = 10 pF, 1.58 V ≤ V_{DD} < 2.7 V	-	2.2	
			C_L = 10 pF, 1.08 V ≤ V_{DDIO2} < 1.58 V	-	4.7	

1. Specified by design, not tested in production.
2. PB15 and PH3 output and input frequencies must not exceed 16 kHz, PC14 and PC15 output and input frequencies must not exceed 250 kHz, for these I/Os OSPEED must be kept at low speed.
3. The I/O speed is configured using the OSPEED bits, Fm+ is configured in SYSCFG. Refer to the product reference manual for the description.
4. I/O compensation system enabled.

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Figure 25. Output AC characteristics definition



Maximum frequency is achieved with a duty cycle at (45 - 55%) when loaded by the specified capacitance.

MS32132V4

5.3.18 NRST pin characteristics

The NRST pin input driver uses CMOS technology. It is connected to a permanent pull-up resistor, R_{PU}.

Unless otherwise specified, the parameters given in *Table 79* are at ambient temperature and under the supply voltage conditions summarized in *Table 30*.

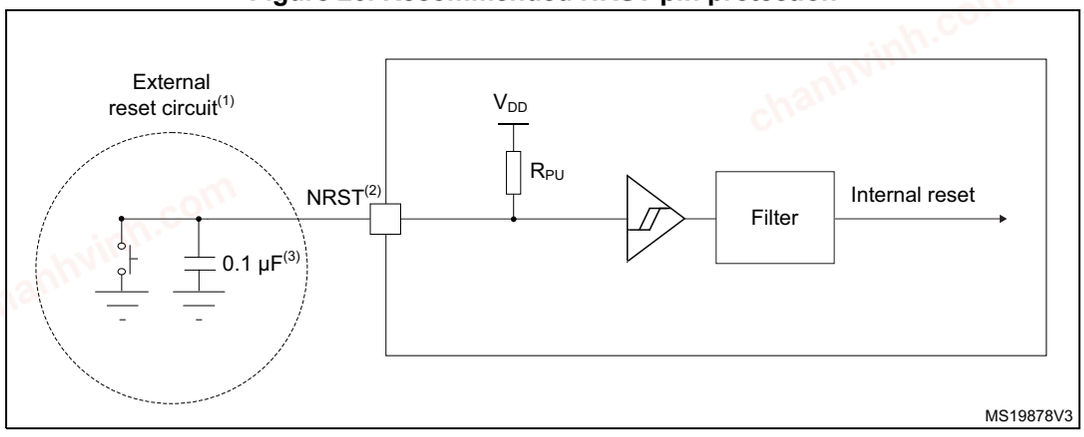
Table 79. NRST pin characteristics(1)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$V_{IL(NRST)}$	Input low level voltage	-	-	-	0.3 x V_{DD}	V
$V_{IH(NRST)}$	Input high level voltage	-	0.7 x V_{DD}	-	-	
$V_{hys(NRST)}$	Schmitt trigger voltage hysteresis	-	-	200	-	mV
R_{PU}	Weak pull-up equivalent resistor(2)	$V_{IN} = V_{SS}$	30	40	50	kΩ
$t_{F(NRST)}$	Input filtered pulse	-	-	-	50	ns
$t_{NF(NRST)}$	Input not-filtered pulse	1.71 V ≤ V_{DD} ≤ 3.6 V	330	-	-	
		1.58 V ≤ V_{DD} < 1.71 V	1000	-	-	

1. Specified by design, not tested in production.
2. The pull-up is designed with a true resistance in series with a switchable PMOS, whose contribution to the series resistance is minimal (~10%).

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Figure 26. Recommended NRST pin protection



1. The reset network protects the device against parasitic resets.
2. The user must ensure that the level on the NRST pin can go below the $V_{IL(NRST)}$ maximum level specified in *Table 79*, or the reset is not taken into account by the device.
3. The external capacitor on NRST must be placed as close as possible to the device.

5.3.19 Extended interrupt and event controller input (EXTI) characteristics

Pulses on the extended interrupt and event controller inputs must have a minimal length, to guarantee they are detected.

Table 80. EXTI input characteristics(1)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$t_{(EXTI)}$	Pulse length to event controller	-	20	-	-	ns

1. Specified by design, not tested in production.

5.3.20 Wake-up pin (WKUP) characteristics

Pulses on the wake-up pin inputs must have a minimal length, to ensure their detection.

Table 81. WKUP input characteristics(1)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$t_{(WKUP)}$	Pulse length to wake up	-	20	-	-	ns

1. Specified by design, not tested in production.

5.3.21 Analog switch booster

Table 82. Analog switches booster characteristics(1)

Symbol	Parameter	Min	Typ	Max	Unit
V_{DD}	Supply voltage	1.6	1.8	3.6	V
$t_{SU(BOOST)}$	Booster startup time	-	-	50	µs
$I_{DD(BOOST)}$	Booster consumption	-	-	125	µA

1. Specified by design, not tested in production.

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5.3.22 12-bit Analog-to-Digital converter (ADC4) characteristics

Unless otherwise specified, the parameters given in the following tables are derived at ambient temperature, and under the f_{HCLK} frequency and supply voltage conditions summarized in *Table 30*.

Note: It is recommended to perform a calibration after each power-up.

Table 83. 12-bit ADC4 characteristics (1)(2)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DDA}	Analog supply voltage	-	1.62	-	3.6	V
V_{REF+}	Positive reference voltage	-	1.0	-	V_{DDA}	
f_{ADC}	ADC clock frequency	-	0.14	-	55	MHz
$DuCy_{ADC}$	ADC clock duty cycle	-	45	-	55	%
f_s	Sampling rate	Resolution 12 bits	0.010	-	2.75	Msps
		Resolution 10 bits	0.012	-	3.05	
		Resolution 8 bits	0.014	-	3.43	
		Resolution 6 bits	0.0175	-	3.92	
t_{TRIG}	External trigger period	Resolution 12 bits	16	-	-	$1/f_{ADC}$
V_{AIN}(3)	Conversion voltage range	-	0	-	V_{REF+}	V
R_{AIN}(4)	External input impedance	Resolution 12 bits, T_j = 130 °C	-	-	2.2	kΩ
		Resolution 10 bits, T_j = 130 °C	-	-	6.8	
		Resolution 8 bits, T_j = 130 °C	-	-	33.0	
		Resolution 6 bits, T_j = 130 °C	-	-	47.0	
C_{ADC}	Internal sample and hold capacitor	-	-	5	-	pF
$t_{ADCVREG_STUP}$	ADC voltage regulator startup time	-	-	-	25	µs
t_{STAB}	ADC power-up time	-	(3 x $1/f_{ADC}$) + 1 conversion			cycle

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Table 83. 12-bit ADC4 characteristics (1)(2) (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
t_{OFF_CAL}	Offset calibration time	-		82		$1/f_{ADC}$
t_{LATR}	Trigger conversion latency	WAIT = 0, AUTOFF = 0, DPD = 0, f_{ADC} = HCLK		4		
		WAIT = 0, AUTOFF = 1, DPD = 0, f_{ADC} = HCLK/2		4		
		WAIT = 0, AUTOFF = 1, DPD = 1, f_{ADC} = HCLK/4		3.75		
t_s	Sampling time	-	1.5	-	814.5	
t_{CONV}	Total conversion time (including sampling time)	Resolution = N bits, VREFPROTEN = 0		t_s + N + 0.5		
		Resolution = N bits, VREFPROTEN = 1, VREFSECSMP = 0	t_s + N + 0.5	-	t_s + N + 1.5	
		Resolution = N bits, VREFPROTEN = 1, VREFSECSMP = 1	t_s + N + 0.5	-	t_s + N + 2.5	
$I_{DDA(ADC)}$	ADC consumption on V_{DDA}	f_s = 2.5 Msps	-	378	-	µA
		f_s = 1 Msps	-	190	-	
		f_s = 10 ksps	-	10	-	
		AUTOFF = 1, DPD = 0, no conversion	-	9	-	
		AUTOFF = 1, DPD = 1, no conversion	-	0.11	-	

1. Specified by design, not tested in production.
2. The voltage booster on the ADC switches must be used when V_{DDA} < 2.4 V (embedded I/O switches).
3. Depending upon the package, V_{REF+} is internally connected to V_{DDA} and V_{REF-} is internally connected to V_{SSA}.
4. The tolerance is two LSBs.

Table 84. Maximum R_{AIN} for 12-bit ADC4(1)(2)(3)

Resolution	R_{AIN} (Ω)	Sampling time (ns)	Sampling cycles at 35 MHz	Sampling cycles at 55 MHz
12 bits	47	276	12.5	19.5
	68	288		
	100	306		
	150	336		

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Table 84. Maximum R_{AIN} for 12-bit ADC4[(1)(2)(3)] (continued)

Resolution	R_{AIN} (Ω)	Sampling time (ns)	Sampling cycles at 35 MHz	Sampling cycles at 55 MHz
12 bits (continued)	220	377	19.5	39.5
	330	442		
	470	526		
	680	650	39.5	
	1000	840		79.5
	1500	1134		
	2200	1643	79.5	814.5
	3300	2395	814.5	
	4700	3342		
	6800	4754		
	10000	6840		
	15000	9967		
	22000	14068		
	33000	19933		N/A
10 bits	47	86	3.5	7.5
	68	90		
	100	95		
	150	108	7.5	
	220	116		
	330	136		
	470	161		12.5
	680	212		
	1000	276	12.5	19.5
	1500	376	19.5	39.5
	2200	516		79.5
	3300	735	39.5	
	4700	1012		
	6800	1423	79.5	814.5
	10000	2040	814.5	814.5
	15000	2978		
	22000	4356		
	33000	6443		
	47000	8925		

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Table 84. Maximum R_{AIN} for 12-bit ADC4[(1)(2)(3)] (continued)

Resolution	R_{AIN} (Ω)	Sampling time (ns)	Sampling cycles at 35 MHz	Sampling cycles at 55 MHz
8 bits	47	45	3.5	3.5
	68	46		
	100	48		
	150	53		
	220	59		
	330	69		7.5
	470	81		
	680	101	7.5	
	1000	130		
	1500	177		12.5
	2200	242	12.5	19.5
	3300	345		
	4700	475	19.5	39.5
	6800	670	39.5	
	10000	963		79.5
	15000	1417	79.5	
	22000	2040		814.5
	33000	2995	814.5	
	47000	4158		
6 bits	47	32	1.5	3.5
	68	32		
	100	33		
	150	35		
	220	37		
	330	41		
	470	49	3.5	
	680	61		
	1000	79		7.5
	1500	106	7.5	
	2200	146		12.5
	3300	207		
	4700	286	12.5	19.5
	6800	404	19.5	39.5
	10000	584	39.5	

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Table 84. Maximum R_{AIN} for 12-bit ADC4(1)(2)(3) (continued)

Resolution	R_{AIN} (Ω)	Sampling time (ns)	Sampling cycles at 35 MHz	Sampling cycles at 55 MHz
6 bits (continued)	22000	1250	79.5	79.5
	33000	1853		814.5
	47000	2607	814.5	

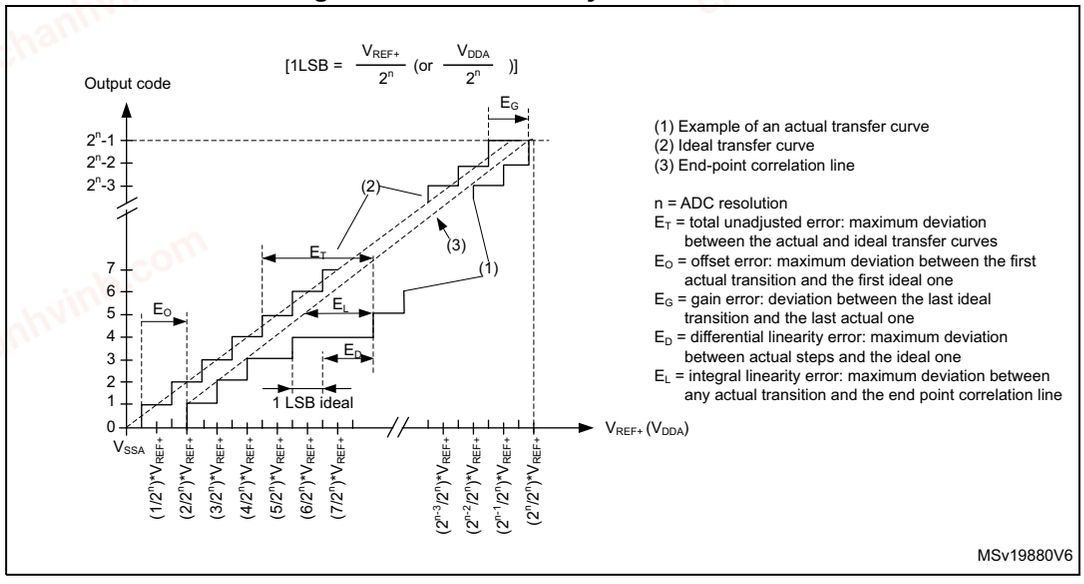
1. Specified by design, not tested in production.
2. BOOSTEN and ANASWVDD configured according to V_{DD} and V_{DDA} levels.
3. Values without external capacitance.

Table 85. 12-bit ADC4 accuracy(1)(2)(3)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
ET	Total unadjusted error	-	-	±3	±7.5	LSB
EO	Offset error		-	±2	±5.5	
EG	Gain error		-	±2	±6.5	
ED	Differential linearity error		-	-0.9/+1.0	-0.9/+1.5	
EL	Integral linearity error		-	±2	±3.5	
ENOB	Effective number of bits		9.9	10.9	-	bits
SINAD	Signal-to-noise and distortion ratio		61.4	67.4	-	dB
SNR	Signal-to-noise ratio		61.6	67.5	-	
THD	Total harmonic distortion		-	-74	-70	

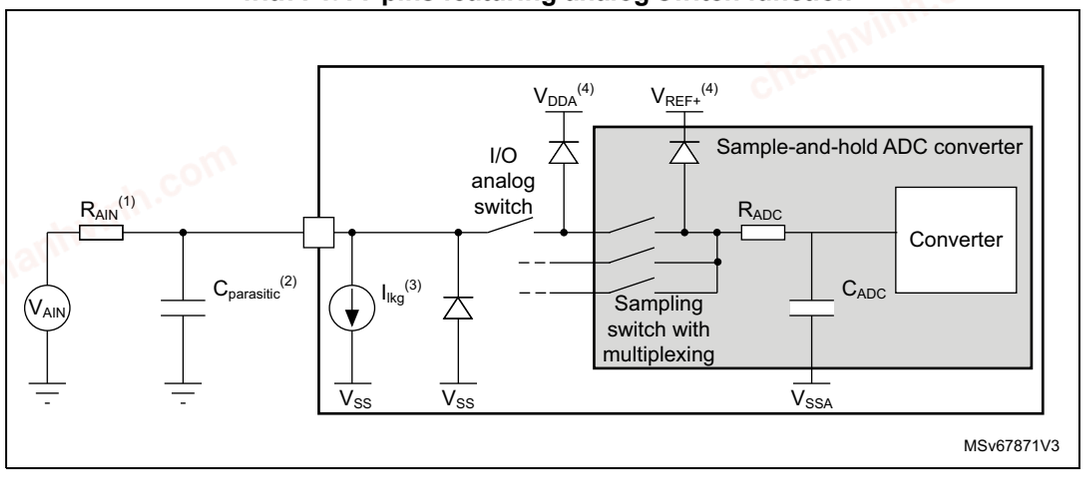
1. Evaluated by characterization, not tested in production.
2. DC accuracy values are measured after internal calibration.
3. The I/O analog switch voltage booster is enabled when V_{DDA} < 2.4 V (resolution = 12 bits, no oversampling).

Figure 27. ADC accuracy characteristics



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Figure 28. Typical connection diagram when using the ADC with FT/TT pins featuring analog switch function



1. Refer to *Table 83* for the values of R_{AIN} and C_{ADC}.
2. $C_{parasitic}$ represents the PCB capacitance (dependent on soldering and PCB layout quality) plus the pad capacitance (refer to *Table 75* for the value of the pad capacitance). A high $C_{parasitic}$ value downgrades the conversion accuracy. As a remedy, reduce f_{ADC}.
3. Refer to *Table 75* for the values of I_{lkg}.
4. Refer to *Figure 18*, *Figure 19*, and *Figure 20*.

5.3.23 Temperature sensor characteristics

Table 86. Temperature sensor characteristics

Symbol	Parameter	Min	Typ	Max	Unit
T_L(1)(2)	V_{SENSE} linearity with temperature	-	-	1.3	°C
Avg_Slope(3)	Average slope	2	2.5	3.0	mV/ °C
$V_{SENSE30}$(4)	V_{SENSE} at V_{REF+} = V_{DDA} = 3.0 V (±10 mV) and 30 °C (±1 °C)	700	742	800	mV
($V_{continous0}$ - $V_{sampling}$)(2)	Voltage difference between continuous and sampling modes(5)	-10	-	+4	mV
$t_{START(TS_BUF)}$(2)	Sensor buffer startup time	-	1	10	µs
t_{S_temp}(2)	ADC sampling time when reading the temperature	13	-	-	µs
$I_{DD(TS)}$(2)	Consumption from V_{DD}, when selected by ADC	-	14	20	µA

1. V_{SENSE} linearity depends upon calibration points. When using TS_CALx calibration points, linearity within the calibration limits is degraded by ±5 °C. Linearity outside the calibration limits is degraded more, due to the extrapolation.
2. Specified by design, not tested in production.
3. Evaluated by characterization, not tested in production, unless otherwise specified.
4. The $V_{SENSE30}$ ADC4 conversion result is stored in the TS_CAL1 field.
5. The temperature sensor is in continuous mode when the regulator is in range 1, in sampling mode when the regulator is in range 2 or the device is in Stop 1 mode.

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5.3.24 V_{CORE} monitoring characteristics

Table 87. V_{CORE} monitoring characteristics(1)

Symbol	Parameter	Min	Typ	Max	Unit
T_{S_VCORE}	ADC sampling time when reading the V_{CORE} voltage	1	-	-	µs

1. Specified by design, not tested in production.

5.3.25 Voltage reference buffer characteristics

Table 88. VREFBUF characteristics(1)

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
V_{DDA}	Analog supply voltage	Normal mode	VRS = 000	1.8	-	3.6	V
			VRS = 001	2.1	-		
			VRS = 010	2.4	-		
			VRS = 011	2.8	-		
		Degraded mode(2)	VRS = 000	1.62	-	1.8	
			VRS = 001		-	2.1	
			VRS = 010		-	2.4	
			VRS = 011		-	2.8	
V_{REFBUF_OUT}(3)	Voltage reference buffer output	Normal mode at V_{DDA} = 3 V, T_J = 30 °C, I_{load} = 10 µA	VRS = 000	1.496	1.5	1.504	
			VRS = 001	1.795	1.8	1.805	
			VRS = 010	2.042	2.048	2.054	
			VRS = 011	2.493	2.5	2.507	
		Degraded mode(2)	VRS = 000	Min (V_{DDA} - 0.15, 1.496)	-	1.504	
			VRS = 001	Min (V_{DDA} - 0.15, 1.795)	-	1.805	
			VRS = 010	Min (V_{DDA} - 0.15, 2.042)	-	2.054	
			VRS = 011	Min (V_{DDA} - 0.15, 2.493)	-	2.507	
TRIM	Trim step	-		0.1	0.175	0.25	%
C_L	Load capacitor(4)	-		0.5	1.10	1.50	µF
esr	C_L equivalent serial resistor	-		-	-	2	Ω
I_{load}	Static load current	-		-	-	4	mA
R_{PD}	Pull-down resistance	-		-	-	400	Ω
I_{line_reg}	Line regulation	$V_{DDAmin} \le V_{DDA} \le 3.6$ V, Normal mode, 500 µA ≤ I_{load} ≤ 4 mA		±0.016	±0.033	±0.053	%
I_{load_reg}	Load regulation(5)	Normal mode, 500 µA ≤ I_{load} ≤ 4 mA		-	50	400	ppm/mA

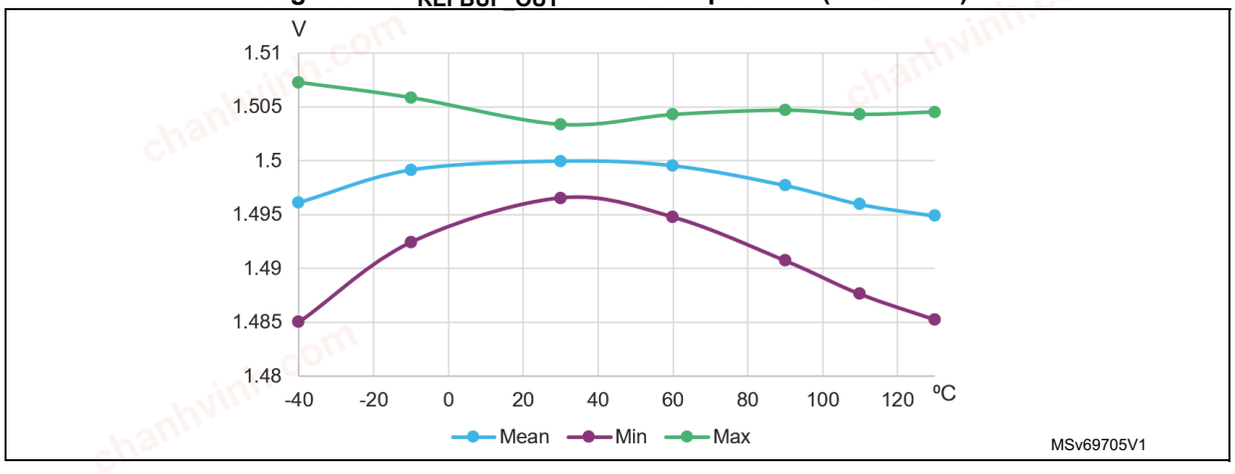
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Table 88. VREFBUF characteristics(1) (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
T_{Coeff}	Temperature coefficient	–40 °C < T_J < +130 °C	-	-	$T_{coeff_vrefint}$ + 50	ppm/ °C
PSRR	Power supply rejection	DC	-	65	-	dB
		100 kHz	-	30	-	
t_{START}	Startup time	C_L = 0.5 µF	-	110	200	µs
		C_L = 1.1 µF	-	240	350	
		C_L = 1.5 µF	-	320	500	
I_{INRUSH}	Control of DC current drive on V_{REFBUF_OUT} during startup phase (6)	-	-	8	11	mA
I_{DDA} (VREFBUF)	Consumption from V_{DDA}	I_{load} = 0 µA	-	14	18	µA
		I_{load} = 500 µA	-	16	20	
		I_{load} = 4 mA	-	42	50	

1. Specified by design and not tested in production, unless otherwise specified.
2. In degraded mode, the voltage reference buffer cannot accurately maintain the output voltage (V_{DDA} - drop voltage).
3. Evaluated by characterization. Not tested in production.
4. The capacitive load must include a 100 nF capacitor to cut off the high-frequency noise.
5. The load regulation value only takes into account the die and package resistance. The parasitic resistance on PCB degrades this value.
6. To correctly control the VREFBUF inrush current during startup phase and scaling change, the V_{DDA} voltage must be in the range of [1.8 V-3.6 V], [2.1 V-3.6 V], [2.4 V-3.6 V], and [2.8 V-3.6 V] for, respectively, VRS = 000, 001, 010, and 011.

Figure 29. V_{REFBUF_OUT} versus temperature (VRS = 000)



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Figure 30. V_{REFBUF_OUT} versus temperature (VRS = 001)

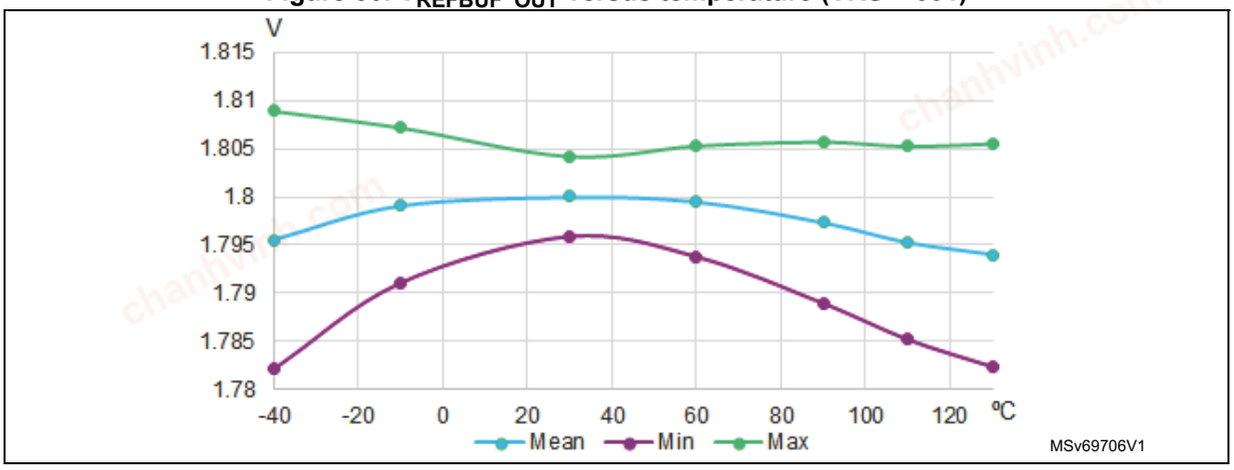


Figure 31. V_{REFBUF_OUT} versus temperature (VRS = 010)

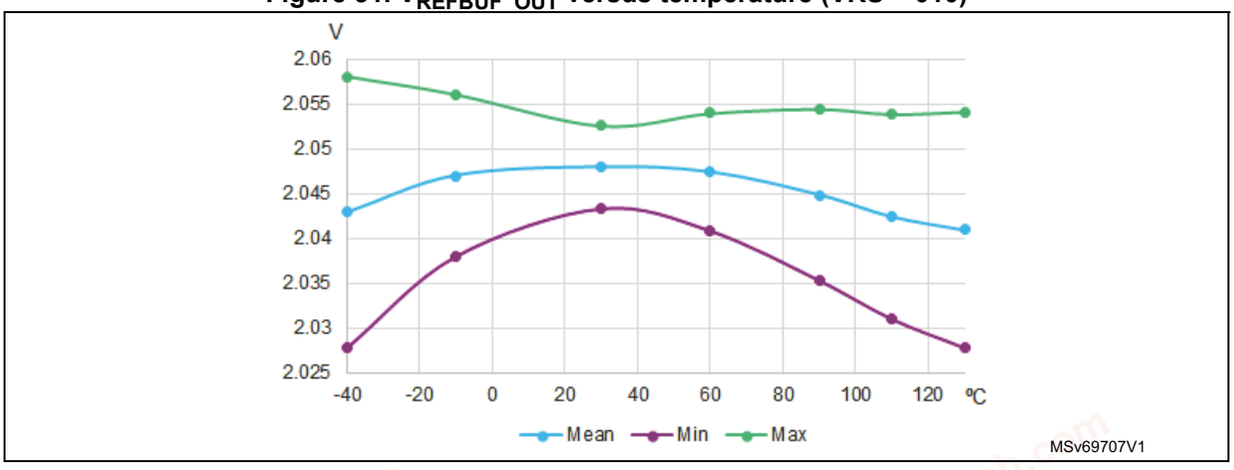
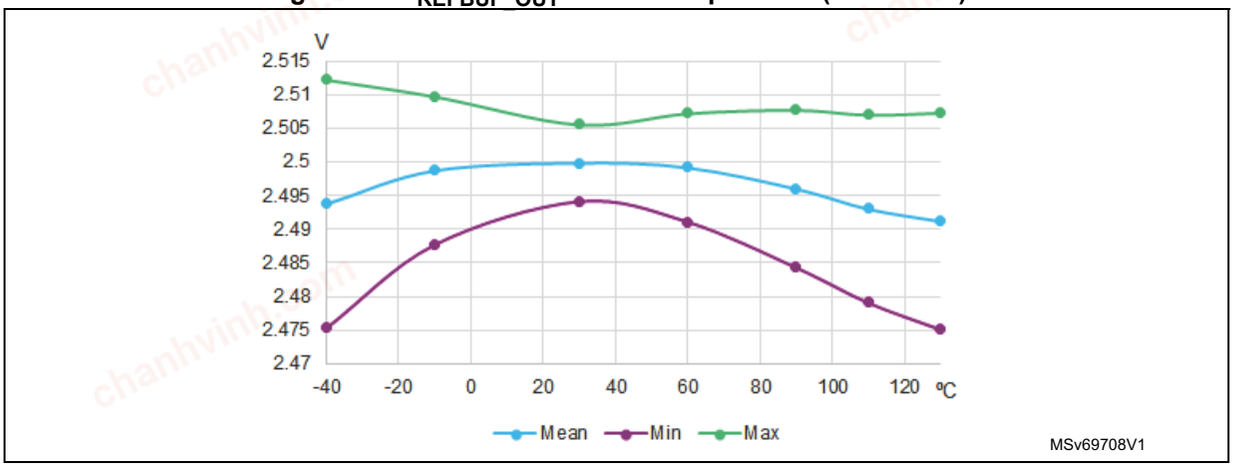


Figure 32. V_{REFBUF_OUT} versus temperature (VRS = 011)



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5.3.26 Comparator characteristics

Table 89. COMP characteristics(1)(2)

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
V_{DDA}	Analog supply voltage	-		1.58	-	3.6	V
V_{IN}	Input voltage range	-		0	-	V_{DDA}	V
V_{REFINT}	Scaler input voltage	-			(3)		V
V_{SC}	Scaler offset voltage	-		-	±5	±10	mV
$I_{DDA(SCALER)}$	Static consumption from V_{DDA}	Scaler bridge disabled(4)		-	0.20	0.25	µA
		Scaler bridge enabled(5)		-	0.7	1	
t_{START_SCALER}	Scaler startup time	-		-	130	220	µs
t_{START}(6)	Startup time to reach propagation delay specification	High-speed mode		-	-	8	µs
		Intermediate mode		-	-	12	
		Medium mode		-	-	16	
		Ultra-low-power mode		-	-	60	
t_D(6)	Propagation delay for 200 mV step with 100 mV overdrive	High-speed mode		-	50	100	ns
		Intermediate mode		-	240	490	
		Medium mode		-	400	740	
		Ultra-low-power mode		-	4	7.5	µs
V_{offset}(6)	Offset error	Full common mode range		-	±8	±20	mV
V_{hys}(6)	Hysteresis	No hysteresis		-	0	-	mV
		Low hysteresis		-	13	-	
		Medium hysteresis		-	26	-	
		High hysteresis		-	39	-	
I_{bias}(6)	Input bias current	-			(7)		nA
$I_{DDA(COMP)}$(6)	Consumption from V_{DDA}	High-speed mode	Static	-	43	72	µA
			With 50 kHz ±100 mV overdrive square signal	-	44	73	
		Intermediate mode	Static	-	8.5	14	
			With 50 kHz ±100 mV overdrive square signal	-	9	15	
		Medium mode	Static	-	4.0	7.0	
			With 50 kHz ±100 mV overdrive square signal	-	4.5	7.5	
		Ultra-low-power mode	Static	-	0.38	1.05	
			With 50 kHz ±100 mV overdrive square signal	-	1.5	2.5	

1. Specified by design, not tested in production, unless otherwise specified.
2. Input capacitance is negligible when compared to the I/O capacitance.

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3. Refer to *Table 43: Embedded internal voltage reference*.
4. No V_{REFINT} division, includes only buffer consumption.
5. V_{REFINT} division, includes resistor bridge and buffer consumption.
6. Evaluated by characterization, not tested in production.
7. Mostly I/O leakage when used in analog mode. Refer to I_{lkg} parameter in *Table 75: I/O static characteristics*.

5.3.27 Timer characteristics

The parameters given in *Table 90*, *Table 91*, and *Table 92* are specified by design. Refer to *Section 4.2* for details on the input/output alternate function characteristics (output compare, input capture, external clock, PWM output).

Table 90. TIMx(1) characteristics(2)

Symbol	Parameter	Conditions	Min	Max	Unit
$t_{res(TIM)}$	Timer resolution time	-	1	-	$t_{TIMxCLK}$
		$f_{TIMxCLK}$ = 100 MHz	10	-	ns
f_{EXT}	Timer external clock frequency on CH1 to CH4	-	0	$f_{TIMxCLK}/2$	MHz
		$f_{TIMxCLK}$ = 100 MHz	0	50	
Res_{TIM}	Timer resolution	TIM1, TIM3, TIM16, TIM17	-	16	bit
		TIM2, TIM4	-	32	
$t_{COUNTER16}$	16-bit counter period	-	1	2^{16}	$t_{TIMxCLK}$
		$f_{TIMxCLK}$ = 100 MHz	0.01	655.36	µs
$t_{COUNTER32}$	32-bit counter period	-	1	2^{32}	$t_{TIMxCLK}$
		$f_{TIM2CLK}$ = 100 MHz	0,01	42.94	s

1. TIMx is used as a general term, where x stands for 1, 2, 3, 4, 16, or 17.
2. Specified by design, not tested in production.

Table 91. IWDG min/max timeout period at 32 kHz(1)(2)

Prescaler divider	PR[3:0] bits	Min timeout RL[11:0] = 0x002	Max timeout RL[11:0] = 0xFFF	Unit
/4	0	0.325	512	ms
/8	1	0.750	1024	
/16	2	1.500	2048	
/32	3	3.0	4096	
/64	4	6.0	8192	
/128	5	12.0	16384	
/256	6	24.0	32768	
/512	7	48.0	65536	
/1024	Others	96.0	131072	

1. The exact timings depend upon the phasing of the APB interface clock vs. the IWDG kernel clock, hence there is always a full kernel clock period of uncertainty.
2. Specified by design, not tested in production.

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Table 92. WWDG min/max timeout value at 100 MHz (PCLK)

Prescaler divider	WDGTB[2:0]	Min timeout value	Max timeout value	Unit
/1	0	0.040	1.621	ms
/2	1	0.081	5.242	
/4	2	0.163	10.485	
/8	3	0.327	20.971	
/16	4	0.655	41.943	
/32	5	1.310	83.886	
/64	6	2.621	167.772	
/128	7	5.242	335.544	

5.3.28 I2C interface characteristics

The I2C interface meets the timings requirements of the I^2C-bus specification and user manual rev. 03 for:

- Standard-mode (Sm): bit rate up to 100 kbit/s
- Fast-mode (Fm): bit rate up to 400 kbit/s
- Fast-mode Plus (Fm+): bit rate up to 1 Mbit/s.

The I2C timings requirements are specified by design, not tested in production, when the I2C peripheral is properly configured (refer to product reference manual).

The SDA and SCL I/O requirements are met with the following restriction: the SDA and SCL I/O pins are not “true” open-drain. When configured as open-drain, the PMOS connected between the I/O pin and V_{DD} is disabled, but is still present. Only FT_f I/O pins support Fm+ low level output current maximum requirement. Refer to *Section 5.3.17* for I2C I/O characteristics.

All I^2C SDA and SCL I/Os embed an analog filter, refer to *Table 93* for its characteristics.

Table 93. I2C analog filter characteristics(1)

Symbol	Parameter	Min	Max	Unit
t_{AF}	Maximum pulse width of spikes suppressed by the analog filter	50(2)	190(3)	ns

1. Specified by design, not tested in production.
2. Spikes with widths below t_{AF} min are filtered.
3. Spikes with widths above t_{AF} max are not filtered.

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5.3.29 USART characteristics

Unless otherwise specified, the parameters given in *Table 94* are derived under the ambient temperature, f_{PCLKx} frequency and V_{DD} supply voltage conditions summarized in *Table 30*, with the following configuration:

- Output speed set to OSPEEDRy[1:0] = 10
- Capacitive load C_L = 30pF
- Measurement points are done at 0.5 V_{DD}
- I/O compensation cell activated
- Voltage scaling range 1

Refer to *Section 4.2* for more details on the input/output alternate function characteristics (NSS, CK, TX, RX for USART).

Table 94. USART characteristics(1)

Symbol	Parameter	Conditions	Min	Typ 3.3 V	Max	Unit
f_{CK}	USART clock frequency	Master mode, 1.71 V ≤ V_{DD} ≤ 3.6 V	-	-	12.5	MHz
		Slave receiver, 1.71 V ≤ V_{DD} ≤ 3.6 V	-	-	33	
		Slave transmitter, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	-	32	
		Slave transmitter, 1.71 V ≤ V_{DD} < 2.7 V	-	-	22.5	
$t_{su(NSS)}$	NSS setup time	Slave mode	t_{ker}(2) + 2	-	-	ns
$t_{h(NSS)}$	NSS hold time	Slave mode	4	-	-	
$t_{w(CKH)}$ $t_{w(CKL)}$	CK high and low time	Master mode	$(1/f_{CK}) / 2 - 1$	$(1/f_{CK}) / 2$	$(1/f_{CK}) / 2 + 1$	
$t_{su(RX)}$	Data input setup time	Master mode	24	-	-	
		Slave mode	2	-	-	
$t_{h(RX)}$	Data input hold time	Master mode	1	-	-	
		Slave mode	0	-	-	
$t_{v(TX)}$	Data output valid time	Slave mode, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	13	15.5	
		Slave mode, 1.71 V ≤ V_{DD} < 2.7 V	-		22	
		Master mode	-	1	-	
$t_{h(TX)}$	Data output hold time	Slave mode	10	-	-	
		Master mode	0	-	-	

1. Evaluated by characterization, not tested in production, unless otherwise specified.
2. t_{ker} is the usart_ker_ck_pres clock period.

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Figure 33. USART timing diagram in master mode

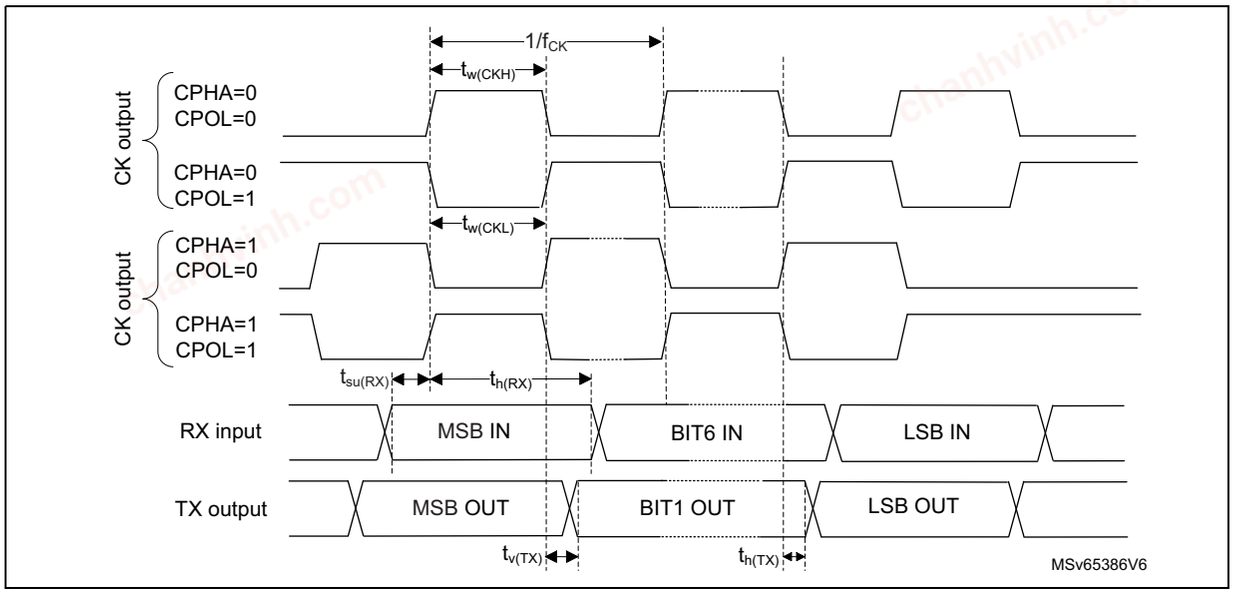
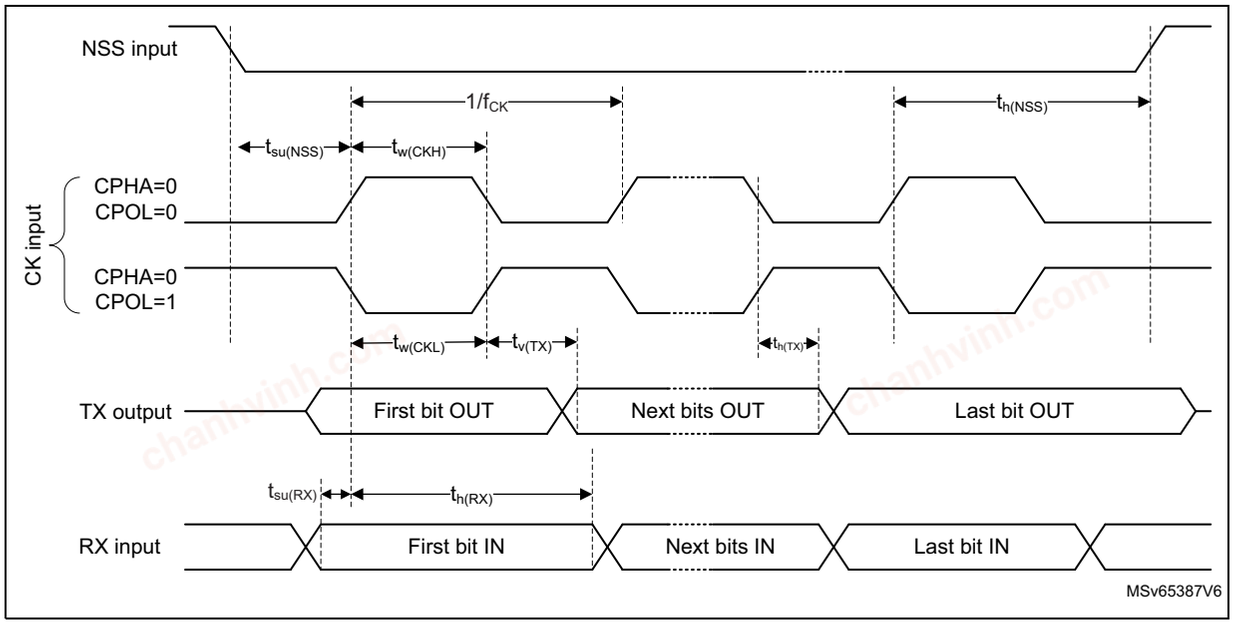


Figure 34. USART timing diagram in slave mode



5.3.30 SPI characteristics

Unless otherwise specified, the parameters given in *Table 95* are under the ambient temperature, f_{PCLKx} frequency and supply voltage conditions summarized in *Table 30*, with the following configuration:

- Output speed is set to OSPEEDRy[1:0] = 10
- Capacitive load C_L = 30 pF
- Measurement points are done at 0.5 V_{DD}
- I/O compensation cell activated

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Refer to *Section 4.2* for more details on the input/output alternate function characteristics (NSS, SCK, MOSI, MISO for SPI).

Table 95. SPI characteristics(1)

Symbol	Parameter	Conditions	Min	Typ 3.3 V	Max	Unit
f_{SCK}	Clock frequency	Master receiver mode 2.7 V ≤ V_{DD} ≤ 3.6 V	-	-	50	MHz
		Master receiver mode 1.71 V ≤ V_{DD} < 2.7 V			33	
		Master transmitter mode 2.7 V ≤ V_{DD} < 3.6 V			50	
		Master transmitter mode 1.71 V ≤ V_{DD} < 2.7 V			33	
		Slave receiver mode 1.71 V ≤ V_{DD} ≤ 3.6 V			50	
		Slave transmitter mode 2.7 V ≤ V_{DD} ≤ 3.6 V, voltage range 1			30(2)	
		Slave transmitter mode 1.71 V ≤ V_{DD} < 2.7 V, voltage range 1			21(2)	
		Slave transmitter mode 1.71 V ≤ V_{DD} ≤ 3.6 V, voltage range 2			16	
$t_{su(NSS)}$	NSS setup time	Slave mode	4 × T_{pclk}	-	-	ns
$t_{h(NSS)}$	NSS hold time	Slave mode	2 × T_{pclk}	-	-	
$t_{w(SCKH)}$ $t_{w(SCKL)}$	SCK high and low time	Master mode	t_{SCK}(3)/2 - 1	t_{SCK}(3)/2	t_{SCK}(3)/2 + 1	
$t_{su(MI)}$	Data input setup time	Master mode	2	-	-	ns
$t_{su(SI)}$		Slave mode	1	-	-	
$t_{h(MI)}$	Data input hold time	Master mode	3	-	-	
$t_{h(SI)}$		Slave mode	1.5	-	-	
$t_{a(SO)}$	Data output access time	Slave mode	9.5	13	23	
$t_{dis(SO)}$	Data output disable time		6	8.5	12	

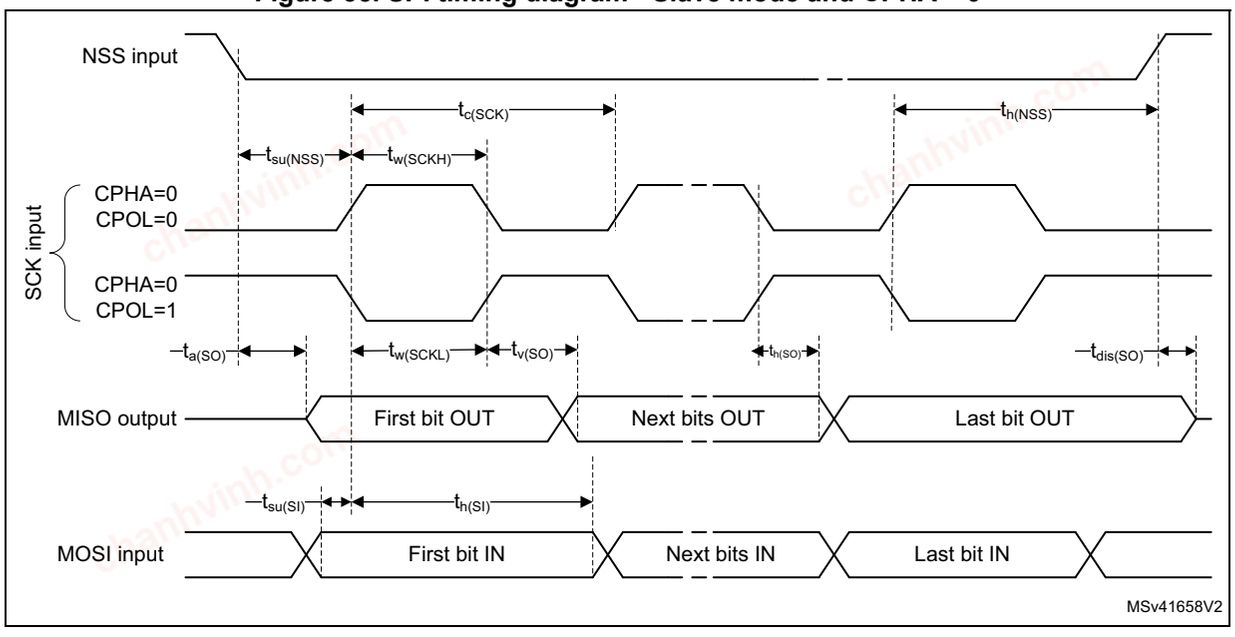
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Table 95. SPI characteristics(1) (continued)

Symbol	Parameter	Conditions	Min	Typ 3.3 V	Max	Unit
$t_{v(SO)}$	Data output valid time	Slave mode (after enable edge) 2.7 V ≤ V_{DD} ≤ 3.6 V, voltage range 1	-	12.5	16.5	ns
		Slave mode (after enable edge) 1.71 V ≤ V_{DD} < 2.7 V, voltage range 1	-	12.5	23.5	
		Slave mode (after enable edge) 2.7 V ≤ V_{DD} ≤ 3.6 V, voltage range 2	-	17	20.5	
		Slave mode (after enable edge) 1.71 V ≤ V_{DD} < 2.7 V, voltage range 2	-	17	27.5	
$t_{v(MO)}$		Master mode	-	1	2	
$t_{h(SO)}$	Data output hold time	Slave mode	8	-	-	
$t_{h(MO)}$		Master mode	0	-	-	

1. Evaluated by characterization, not tested in production.
2. Maximum frequency in Slave transmitter mode is determined by the sum of $t_{v(SO)}$ and $t_{su(MI)}$, which must fit into SCK low or high phase preceding the SCK sampling edge. This value can be achieved when SPI communicates with a master having $t_{su(MI)}$ = 0 while $Duty_{(SCK)}$ = 50%.
3. t_{SCK} = $t_{spi_ker_ck}$ x baudrate prescaler

Figure 35. SPI timing diagram - Slave mode and CPHA = 0



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Figure 36. SPI timing diagram - Slave mode and CPHA = 1

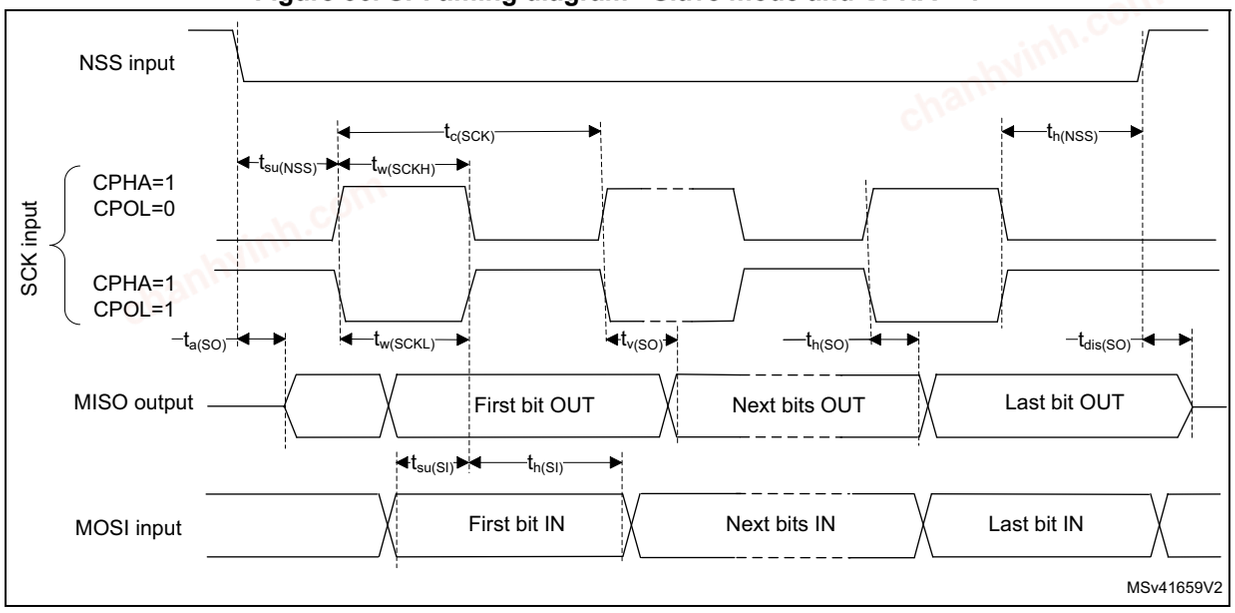
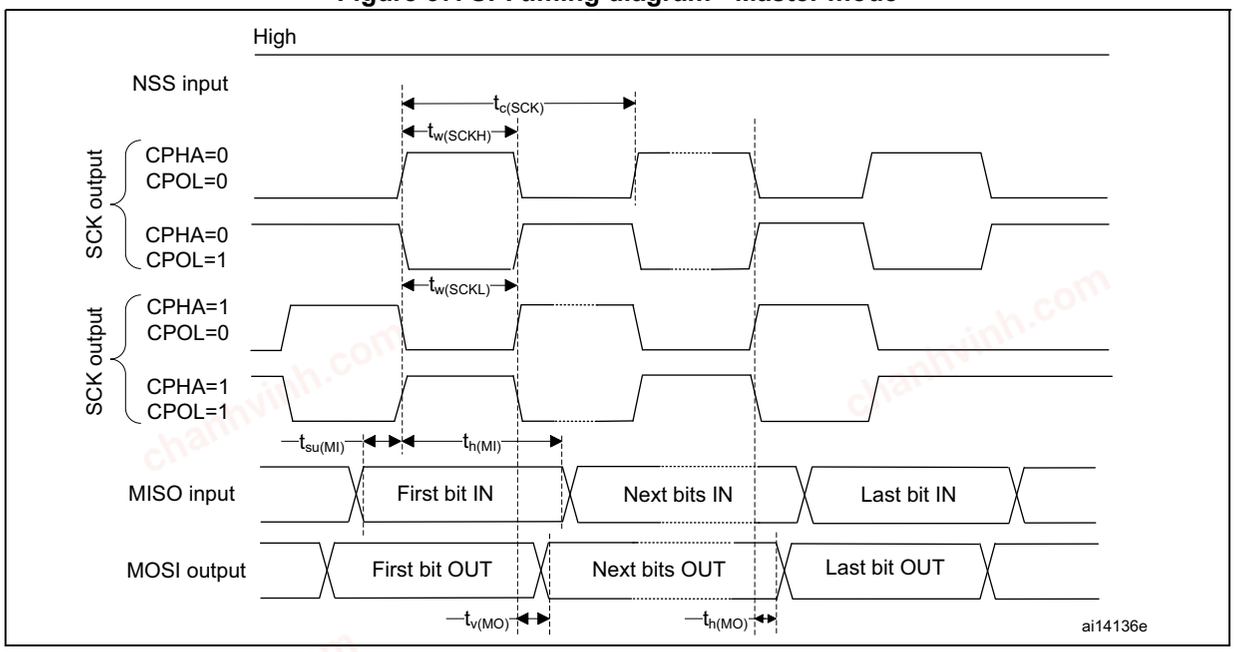


Figure 37. SPI timing diagram - Master mode



5.3.31 SAI characteristics

Unless otherwise specified, the parameters given in *Table 96* are derived from tests performed under the ambient temperature, f_{PCLKx} frequency and V_{DD} supply voltage conditions summarized in *Table 30*, with the following configuration:

- Output speed is set to OSPEEDRy[1:0] = 10
- Capacitive load C_L = 30 pF
- I/O compensation cell activated
- Measurement points are done at CMOS levels: 0.5 V_{DD}

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Refer to *Section 4.2* for more details on the input/output alternate function characteristics (SCK, SD, WS).

Table 96. SAI characteristics(1)(2)

Symbol	Parameter	Conditions	Min	Max	Unit
f_{MCK}	Main clock output	-	-	50	MHz
f_{CK}	Clock frequency	Master transmitter, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	23	
		Master transmitter, 1.71 V ≤ V_{DD} < 2.7 V	-	16.5	
		Master receiver, 1.71 V ≤ V_{DD} ≤ 3.6 V	-	18	
		Slave transmitter, 2.7 V ≤ V_{DD} ≤ 3.6 V Voltage range 1	-	23	
		Slave transmitter, 1.71 V ≤ V_{DD} < 2.7 V Voltage range 1	-	16.5	
		Slave transmitter, 1.71 V ≤ V_{DD} ≤ 3.6 V Voltage range 2	-	12.5	
		Slave receiver, 1.71 V ≤ V_{DD} ≤ 3.6 V	-	50	
$t_{v(FS)}$	F_S valid time	Master mode, 2.7 V ≤ V_{DD} ≤ 3.6 V	-	19.5	ns
		Master mode, 1.71 V ≤ V_{DD} < 2.7 V	-	27.5	
$t_{su(FS)}$	F_S setup time	Slave mode	1	-	
$t_{h(FS)}$	F_S hold time	Master mode	11.5	-	
		Slave mode	1	-	
$t_{su(SD_A_MR)}$	Data input setup time	Master receiver	3.5	-	
$t_{su(SD_B_SR)}$		Slave receiver	3	-	
$t_{h(SD_A_MR)}$	Data input hold time	Master receiver	3	-	
$t_{h(SD_B_SR)}$		Slave receiver	2	-	
$t_{v(SD_B_ST)}$	Data output valid time	Slave transmitter (after enable edge), 2.7 V ≤ V_{DD} ≤ 3.6 V, voltage range 1	-	21.5	
		Slave transmitter (after enable edge), 1.71 V ≤ V_{DD} < 2.7 V, voltage range 1	-	30	
		Slave transmitter (after enable edge), 2.7 V ≤ V_{DD} ≤ 3.6 V, voltage range 2	-	30	
		Slave transmitter (after enable edge), 1.71 V ≤ V_{DD} < 2.7 V, voltage range 2	-	39	
$t_{h(SD_B_ST)}$	Data output hold time	Slave transmitter (after enable edge) Voltage range 1	12	-	
		Slave transmitter (after enable edge) Voltage range 2	21	-	

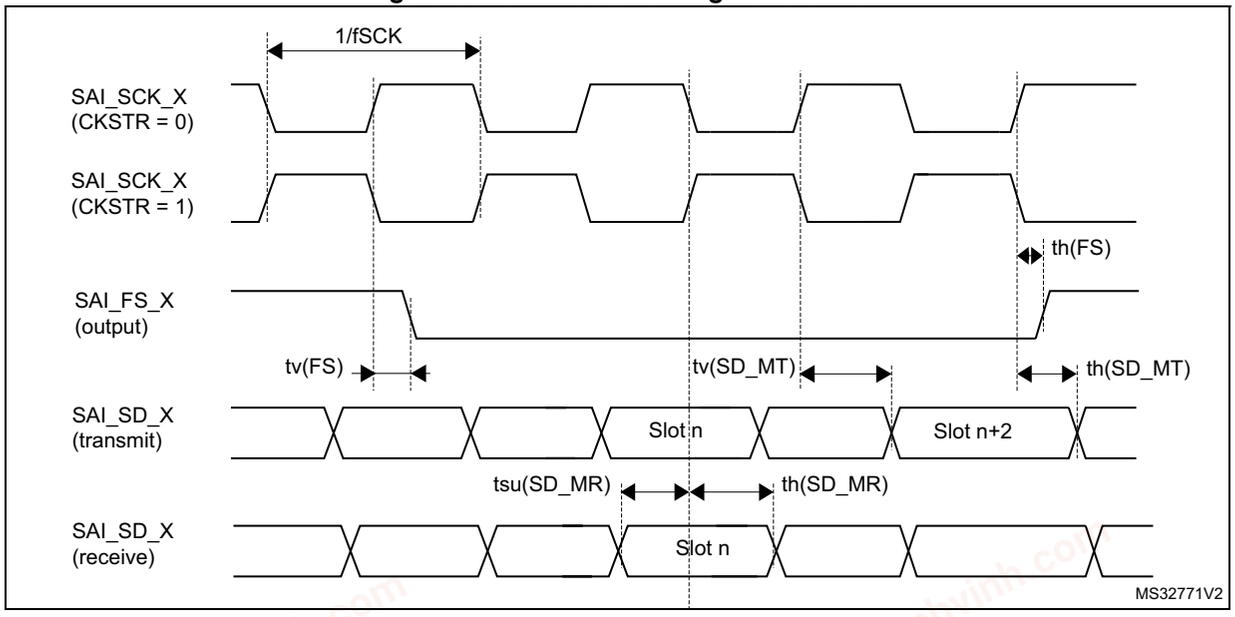
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Table 96. SAI characteristics(1)(2) (continued)

Symbol	Parameter	Conditions	Min	Max	Unit
$t_{v(SD_A_MT)}$	Data output valid time	Master transmitter (after enable edge) 2.7 V ≤ V_{DD} ≤ 3.6 V	-	21.5	ns
		Master transmitter (after enable edge) 1.71 V ≤ V_{DD} < 2.7 V	-	30	
$t_{h(SD_A_MT)}$	Data output hold time	Master transmitter (after enable edge)	10	-	

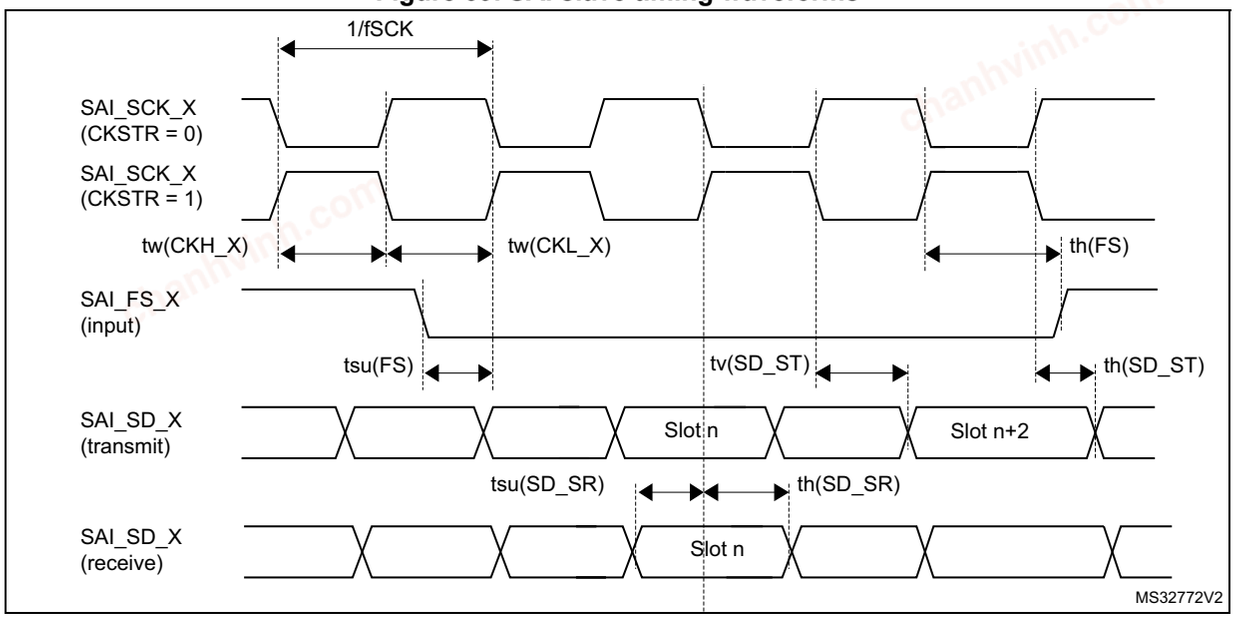
1. Evaluated by characterization - Not tested in production.
2. APB clock frequency must be at least two times the SAI clock frequency.

Figure 38. SAI master timing waveforms



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Figure 39. SAI slave timing waveforms



5.3.32 OTG_HS characteristics

The OTG_HS controller complies with the following specifications:

- USB On-The-Go supplement, revision 2.0
- Universal Serial Bus revision 2.0 specification
- Battery charging specification, revision 1.2

The parameters given in the following tables are derived from tests performed under temperature up to 120 °C and V_{DD} supply voltage conditions summarized in *Table 30*.

Table 97. OTG_HS electrical characteristics(1)

Symbol	Parameter	Condition	Min	Typ	Max	Unit
V_{DDUSB}	USB transceiver operating voltage	-	3.0	-	3.6	V
f_{HCLK}	HSE32 oscillator is used to guarantee proper operation of the OTG_HS interface	-	-	32	-	MHz
R_{PUI}	Embedded USB_DP pull-up value during idle	-	900	1250	1575	Ω
R_{PUR}	Embedded USB_DP pull-up value during reception	-	1425(2)	2250	3090(2)	
R_{PD}	Embedded USB_DP and USB_DM pull-down value	-	14250	-	24800	
Z_{DRV}	Output driver impedance(3)	Driving high or low	40.5(2)	45	49.5(2)	
t_{lr}	Rise time	C_L < 5 pF	0.5(2)	-	-	ns
t_{lf}	Fall time	C_L < 5 pF	0.5(2)	-	-	
t_{lrfm}	Rise/fall time matching	-	80(2)	-	125(2)	%

1. Evaluated by characterization. Not tested in production, unless otherwise specified.
2. Specified by design, not tested in production.
3. No external termination series resistors are required on USB_DP (D+) and USB_DM (D-). The matching impedance is already included in the embedded driver.

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Table 98. OTG_HS DC electrical characteristics(1)

Symbol	Parameter	Condition	Min	Typ	Max	Unit
V_{hssq}	High-speed squelch detection threshold	-	100(2)	-	150	mV
V_{hsdsc}	High-speed disconnect detection threshold	-	525	-	625	
V_{hsdif}	High-speed differential detection threshold	-	100	-	-	
V_{hscm}	High-speed data signaling common mode voltage range	-	-50	-	500	
V_{hsoi}	High-speed idle level	-	-10	-	10	
V_{hsoh}	High-speed data signaling high	-	360	-	440	
V_{hsol}	High-speed data signaling low	-	-10	-	10	
$V_{hchirpj}$	Chirp J level	-	700	-	1100	
$V_{hchirpk}$	Chirp K level	-	-900	-	-500	

1. Evaluated by characterization. Not tested in production.
2. 50 mV test waivers from usb.org have been applied.

Table 99. OTG_HS PHY BCD electrical characteristics(1)

Symbol	Parameter	Min	Typ	Max	Unit
$I_{DD(USBBCD)}$	Primary detection mode consumption	-	4.9	5.7	mA
	Secondary detection mode consumption	-	4.8		
R_{DAT_LKG}	Data line leakage resistance	300(2)	-	-	kΩ
V_{DAT_LKG}	Data line leakage voltage	0.0	-	3.6(2)	V
R_{DCP_DAT}	Dedicated charging port resistance across D+/D-	-	-	200(2)	Ω
V_{LGC_HI}	Logic high	2.0		3.6	V
V_{LGC_LOW}	Logic low	-	-	0.8	
V_{LGC}	Logic threshold	0.8	-	2.0	
V_{DAT_REF}	Data detect voltage	0.25(2)	-	0.4(2)	
V_{DP_SRC}	D+ source voltage	0.5	-	0.7	
V_{DM_SRC}	D- source voltage	0.5	-	0.7	
I_{DM_SINK}	D- sink current	25	-	175	µA
I_{DP_SINK}	D+ sink current	25	-	175	
I_{DP_SRC}	Data contact detect current source	7.0	-	13	

1. Evaluated by characterization. Not tested in production, unless otherwise specified.
2. Specified by design. Not tested in production.

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5.3.33 JTAG/SWD interface characteristics

Unless otherwise specified, the parameters given in *Table 100* and *Table 101* are with the following configuration:

- Output speed is set to OSPEEDRy[1:0] = 10
- Capacitive load C = 30 pF
- Measurement points are done at 0.5 x V_{DD}
- I/O compensation cell disabled

Table 100. JTAG characteristics(1)

Symbol	Parameter	Conditions	Min	Typ 3.3 V	Max	Unit
f_{TCK}	TCK clock frequency	$2.7 \le V_{DD} \le 3.6$ V	-	-	21.5	MHz
		$1.71 \le V_{DD} < 2.7$ V	-	-	16.5	
$t_{isu(TMS)}$	TMS input setup time	-	1.5	-	-	ns
$t_{ih(TMS)}$	TMS input hold time	-	6	-	-	
$t_{isu(TDI)}$	TDI input setup time	-	1.5	-	-	
$t_{ih(TDI)}$	TDI input hold time	-	4	-	-	
$t_{ov(TDO)}$	TDO output valid time	$2.7 \le V_{DD} \le 3.6$ V	-	17	23	
		$1.71 \le V_{DD} < 2.7$ V	-	17	29.5	
$t_{oh(TDO)}$	TDO output hold time	-	13	-	-	

1. Evaluated by characterization, not tested in production.

Table 101. SWD characteristics(1)

Symbol	Parameter	Conditions	Min	Typ 3.3 V	Max	Unit
f_{SWCLK}	SWCLK clock frequency	$2.7 \le V_{DD} \le 3.6$ V	-	-	62.5	MHz
		$1.71 \le V_{DD} < 2.7$ V	-	-	34	
$t_{isu(SWDIO)}$	SWDIO input setup time	-	1.5	-	-	ns
$t_{ih(SWDIO)}$	SWDIO input hold time	-	3.5	-	-	
$t_{ov(SWDIO)}$	SWDIO output valid time	$2.7 \le V_{DD} \le 3.6$ V	-	12	16	
		$1.71 \le V_{DD} < 2.7$ V	-	12	29	
$t_{oh(SWDIO)}$	SWDIO output hold time	-	8.5	-	-	

1. Evaluated by characterization, not tested in production.

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Figure 40. JTAG timing diagram

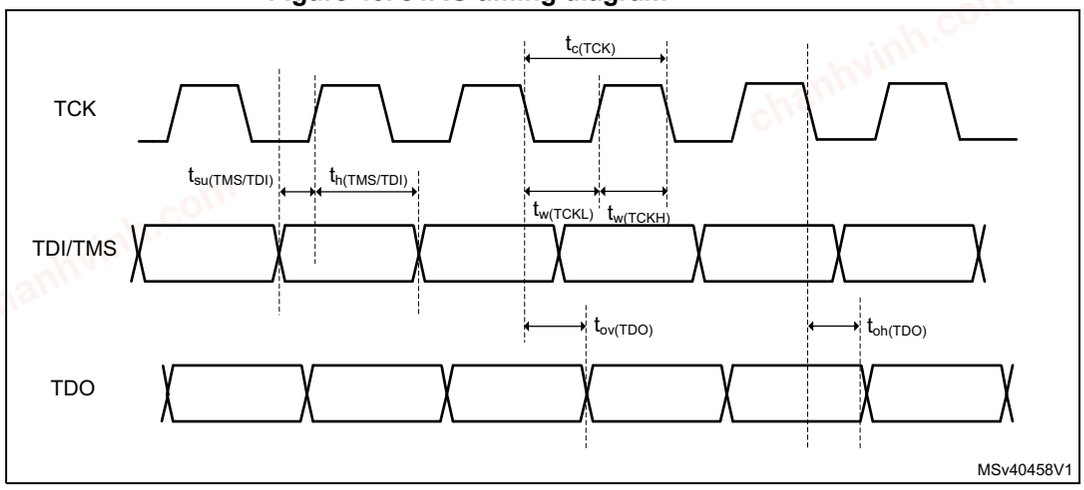
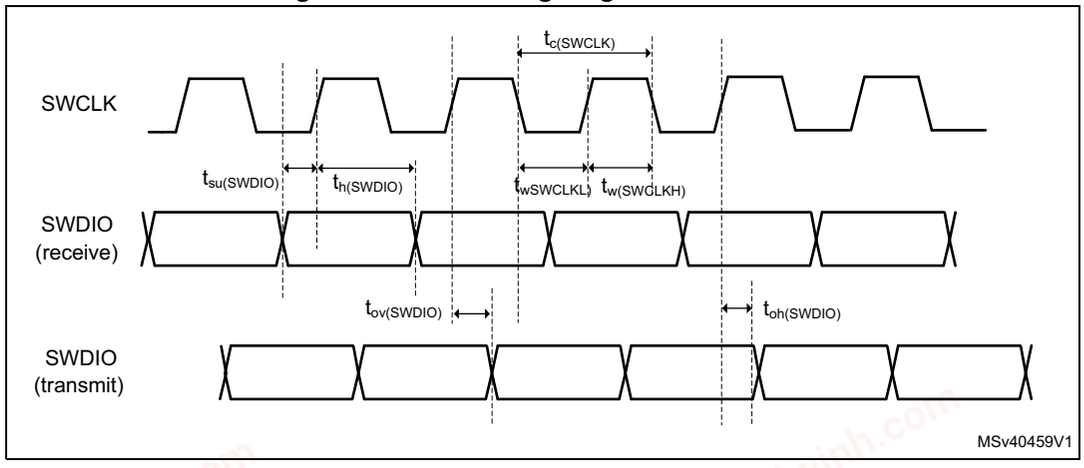


Figure 41. SWD timing diagram



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6 Package information

In order to meet environmental requirements, ST offers these devices in different grades of ECOPACK packages, depending on their level of environmental compliance. ECOPACK specifications, grade definitions and product status are available at: *www.st.com*. ECOPACK is an ST trademark.

6.1 Device marking

Refer to technical note “Reference device marking schematics for STM32 microcontrollers and microprocessors” (TN1433) available on *www.st.com*, for the location of pin 1 / ball A1 as well as the location and orientation of the marking areas versus pin 1 / ball A1.

Parts marked as “ES”, “E” or accompanied by an engineering sample notification letter, are not yet qualified and therefore not approved for use in production. ST is not responsible for any consequences resulting from such use. In no event will ST be liable for the customer using any of these engineering samples in production. ST’s Quality department must be contacted prior to any decision to use these engineering samples to run a qualification activity.

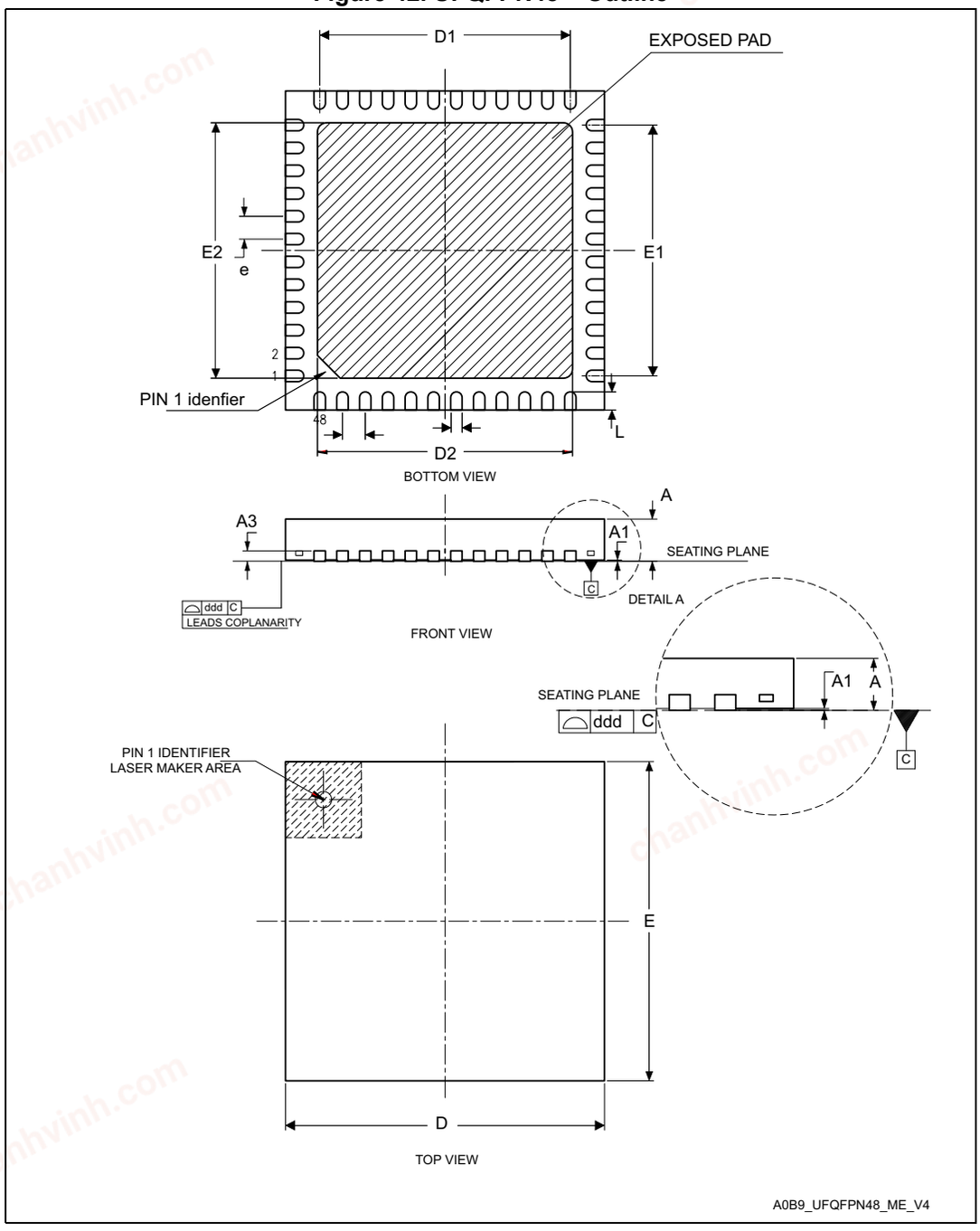
A WLCSP simplified marking example (if any) is provided in the corresponding package information subsection.

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6.2 UFQFPN48 package information (A0B9)

This UFQFPN is a 48-lead, 7 x 7 mm, 0.5 mm pitch, ultra thin fine pitch quad flat package.

Figure 42. UFQFPN48 – Outline



1. Drawing is not to scale.
2. All leads/pads should also be soldered to the PCB to improve the lead/pad solder joint life.
3. There is an exposed die pad on the underside of the UFQFPN48 package. It is recommended to connect and solder this back-side pad to PCB ground.

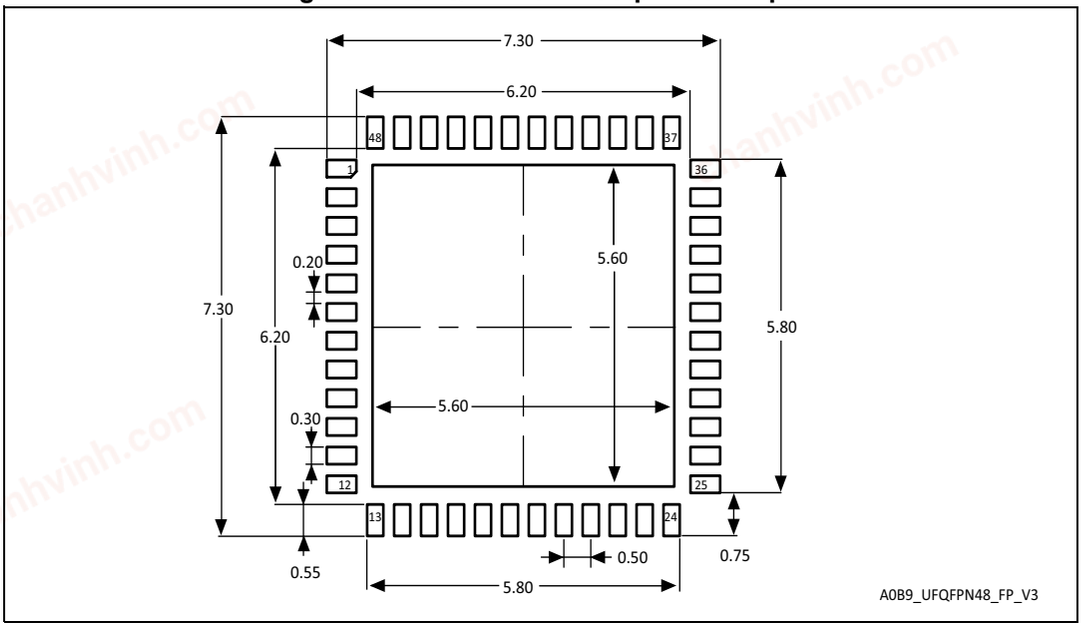
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Table 102. UFQFPN48 – Mechanical data

Symbol	millimeters			inches[1]		
	Min	Typ	Max	Min	Typ	Max
A	0.500	0.550	0.600	0.0197	0.0217	0.0236
A1	0.000	0.020	0.050	0.0000	0.0008	0.0020
A3	-	0.152	-	-	0.0060	-
b	0.200	0.250	0.300	0.0079	0.0098	0.0118
D[2]	6.900	7.000	7.100	0.2717	0.2756	0.2795
D1	5.400	5.500	5.600	0.2126	0.2165	0.2205
D2[3]	5.500	5.600	5.700	0.2165	0.2205	0.2244
E[2]	6.900	7.000	7.100	0.2717	0.2756	0.2795
E1	5.400	5.500	5.600	0.2126	0.2165	0.2205
E2[3]	5.500	5.600	5.700	0.2165	0.2205	0.2244
e	-	0.500	-	-	0.0197	-
L	0.300	0.400	0.500	0.0118	0.0157	0.0197
ddd	-	-	0.080	-	-	0.0031

1. Values in inches are converted from mm and rounded to four decimal digits.
2. Dimensions D and E do not include mold protrusion, not exceed 0.15 mm.
3. Dimensions D2 and E2 are not in accordance with JEDEC.

Figure 43. UFQFPN48 – Footprint example



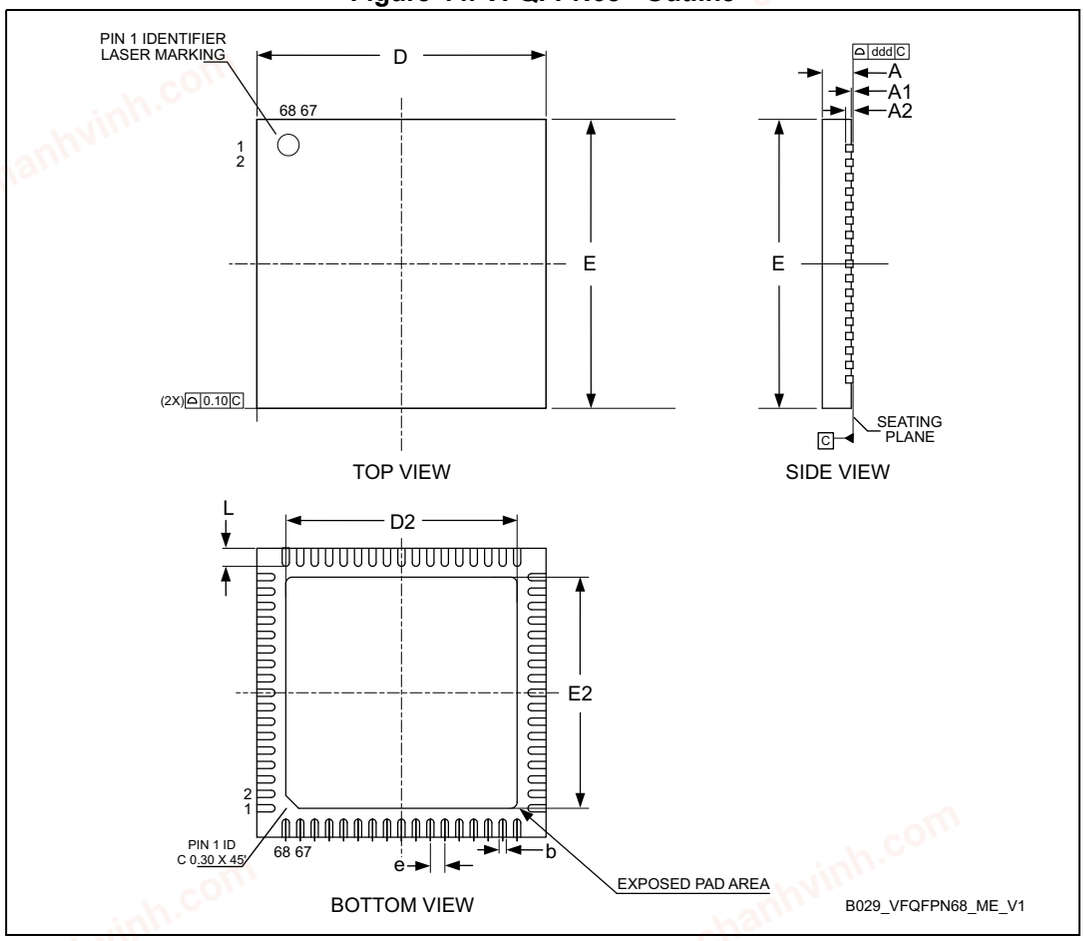
1. Dimensions are expressed in millimeters.

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6.3 VFQFPN68 package information (B029)

This VFQFPN is a 68 pins, 8 x 8 mm, 0.4 mm pitch, very thin fine pitch quad flat package.

Figure 44. VFQFPN68 - Outline



1. VFQFPN stands for Thermally Enhanced Very thin Fine pitch Quad Flat Packages No lead. Sawed version. Very thin profile: 0.80 < A ≤ 1.00mm.
2. The pin #1 identifier must be existed on the top surface of the package by using indentation mark or other feature of package body. Exact shape and size of this feature is optional.

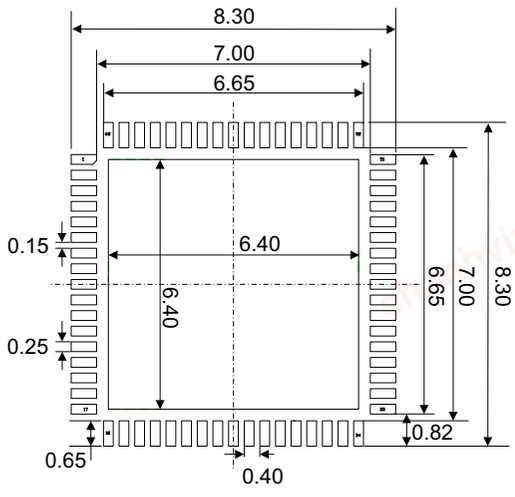
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Table 103. VFQFPN68 - Mechanical data

Symbol	millimeters			inches[1]		
	Min	Typ	Max	Min	Typ	Max
A	0.80	0.90	1.00	0.0315	0.0354	0.0394
A1	0	0.02	0.05	0	0.0008	0.0020
A3	-	0.20	-	-	0.0008	-
b	0.15	0.20	0.25	0.0059	0.0079	0.0098
D	7.85	8.00	8.15	0.3091	0.3150	0.3209
D2	6.30	6.40	6.50	0.2480	0.2520	0.2559
E	7.85	8.00	8.15	0.3091	0.3150	0.3209
E2	6.30	6.40	6.50	0.2480	0.2520	0.2559
e	-	0.40	-	-	0.0157	-
L	0.40	0.50	0.60	0.0157	0.0197	0.0236
ddd	-	-	0.08	-	-	0.0031

1. Values in inches are converted from mm and rounded to 4 decimal digits.

Figure 45. VFQFPN68 - Recommended footprint



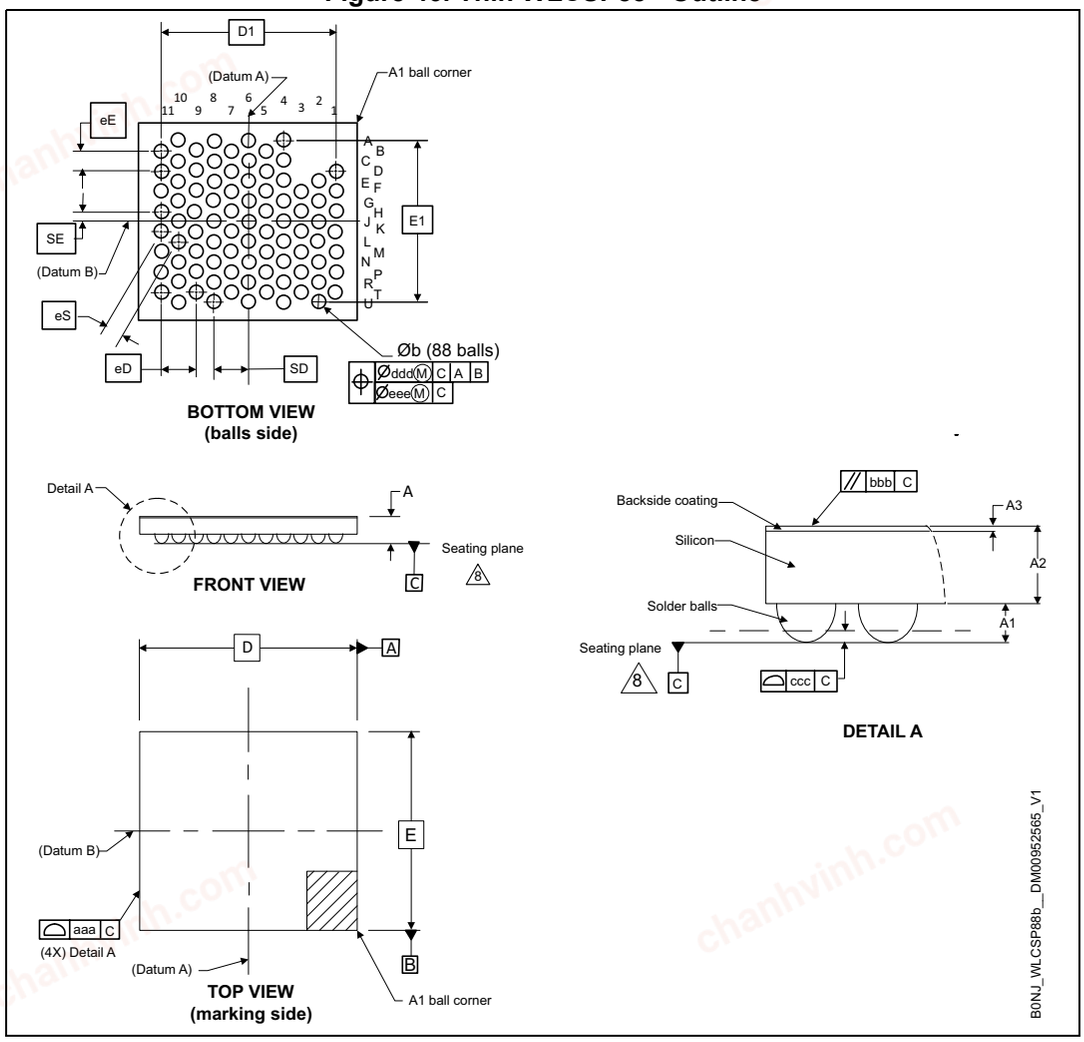
1. Dimensions are expressed in millimeters.

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6.4 Thin WLCSP88 package information (B0NJ)

This WLCSP is a 88-ball, 3.78 x 3.46 mm, 0.35 mm pitch, wafer level chip scale package.

Figure 46. Thin WLCSP88 - Outline



1. Drawing is not to scale.

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Table 104. Thin WLCSP88 - Mechanical data

Symbol	millimeters			inches[1]		
	Min	Typ	Max	Min	Typ	Max
A[2]	-	-	0.50	-	-	0.0197
A1[3]	0.12	-	-	0.0047	-	-
A2	-	0.30	-	-	0.0118	-
A3	-	0.025	-	-	0.0010	-
b[4]	0.20	0.23	0.25	0.0079	0.0091	0.0098
D[5]	3.78 BSC			0.1488 BSC		
D1[5]	3.03 BSC			0.1193 BSC		
E[5]	3.46 BSC			0.1362 BSC		
E1[5]	2.80 BSC			0.1102 BSC		
eD[5][6]	0.61 BSC			0.0240 BSC		
eE[5][6]	0.35 BSC			0.0138 BSC		
eS[5][6]	0.35 BSC			0.0138 BSC		
N[7]	88					
SD[5][8]	0.61 BSC			0.0240 BSC		
SE[5][8]	0.175 BSC			0.0069 BSC		
aaa[9]	0.02			0.0008		
bbb[9]	0.06			0.0024		
ccc[9]	0.03			0.0012		
ddd[9]	0.015			0.0006		
eee[9]	0.05			0.0020		

1. Values in inches are converted from mm and rounded to 4 decimal digits.
2. The profile height A is the distance from the seating plane to the highest point on the package. It is measured perpendicular to the seating plane.
3. A1 is defined as the distance from the seating plane to the lowest point on the package body.
4. Dimension b is measured at the maximum diameter of the terminal (ball) in a plane parallel to Datum C.
5. BSC stands for BASIC dimensions. It corresponds to the nominal value and has no tolerance. For tolerances, refer to form and position table. On the drawing, these dimensions are framed. For the tolerances, refer to form and position values.
6. e represents the solder balls grid pitch(es).
7. N represents the total number of balls.
8. Basic dimensions SD & SE are defining the ball matrix position with respect to datums A and B.
9. Tolerance of form and position drawing

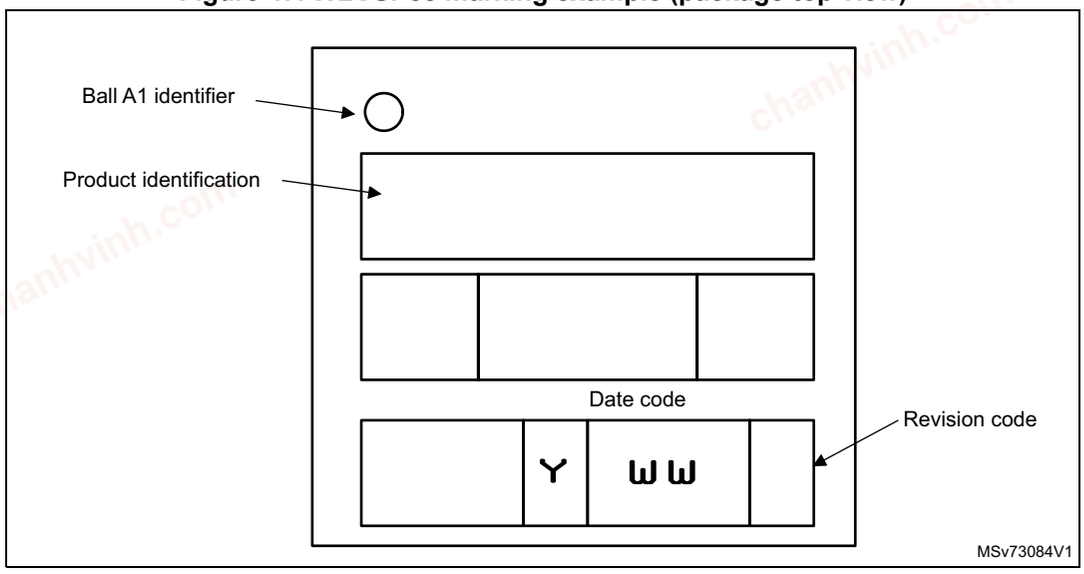
Example of device marking for thin WLCSP88

Figure 47 gives an example of the locations and orientation of the marking areas versus ball A1, and allows engineering samples to be identified.

With the device text markings oriented as shown below, ball A1 is always located at top left.

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Figure 47. WLCSP88 marking example (package top view)

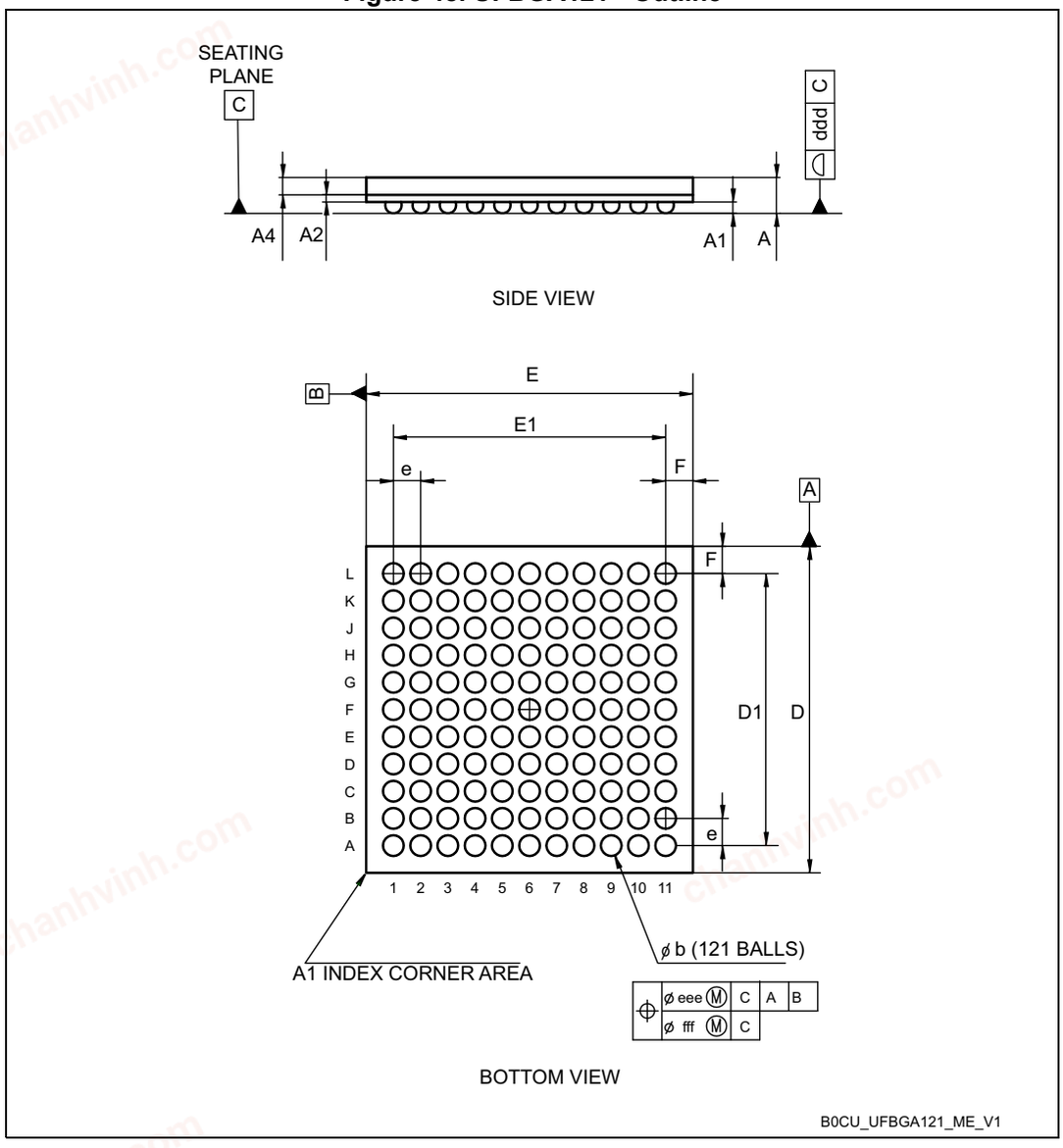


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6.5 UFBGA121 package information (B0CU)

This UFBGA is a 121-ball, 6 x 6 mm, 0.5 mm pitch, fine pitch, square ball grid array package.

Figure 48. UFBGA121 - Outline



1. Drawing is not to scale.
2. - The terminal A1 corner must be identified on the top surface by using a corner chamfer, ink or metalized markings, or other feature of package body or integral heat slug.
   - A distinguishing feature is allowable on the bottom surface of the package to identify the terminal A1 corner. Exact shape of each corner is optional.

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Table 105. UFBGA121 - Mechanical data

Symbol	millimeters			inches[1]		
	Min	Typ	Max	Min	Typ	Max
A[2]	-	-	0.60	-	-	0.0236
A1	-	-	0.11	-	-	0.0043
A2	-	0.13	-	-	0.0051	-
A4	-	0.32	-	-	0.0126	-
b[3]	0.24	0.29	0.34	0.0094	0.0114	0.0134
D	5.85	6.00	6.15	0.2303	0.2362	0.2421
D1	-	5.00	-	-	0.1969	-
E	5.85	6.00	6.15	0.2303	0.2362	0.2421
E1	-	5.00	-	-	0.1969	-
e	-	0.50	-	-	0.0197	-
F	-	0.50	-	-	0.0197	-
ddd	-	-	0.08	-	-	0.0031
eee[4]	-	-	0.15	-	-	0.0059
fff[5]	-	-	0.05	-	-	0.0020

1. Values in inches are converted from mm and rounded to four decimal digits.
2. - UFBGA stands for Ultra-Thin Profile Fine Pitch Ball Grid Array.
   - Ultra Thin profile: 0.50 < A ≤ 0.65 mm / Fine pitch: e < 1.00 mm pitch.
   - The total profile height (Dim A) is measured from the seating plane to the top of the component
   - The maximum total package height is calculated by the following methodology:
   A Max = A1 Typ + A2 Typ + A4 Typ + √ ($A1^2$ + $A2^2$ + $A4^2$ tolerance values)
3. The typical balls diameter before mounting is 0.20 mm
4. The tolerance of position that controls the location of the pattern of balls with respect to datum A and B. For each ball there is a cylindrical tolerance zone eee perpendicular to datum C and located on true position with respect to datum A and B as defined by e. The axis perpendicular to datum C of each ball must lie within this tolerance zone.
5. The tolerance of position that controls the location of the balls within the matrix with respect to each other. For each ball there is a cylindrical tolerance zone fff perpendicular to datum C and located on true position as defined by e. The axis perpendicular to datumC of each ball must lie within this tolerance zone. Each tolerance zone fff in the array is contained entirely in the respective zone eee above. The axis of each ball must lie simultaneously in both tolerance zones.

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Figure 49. UFBGA121 - Footprint example

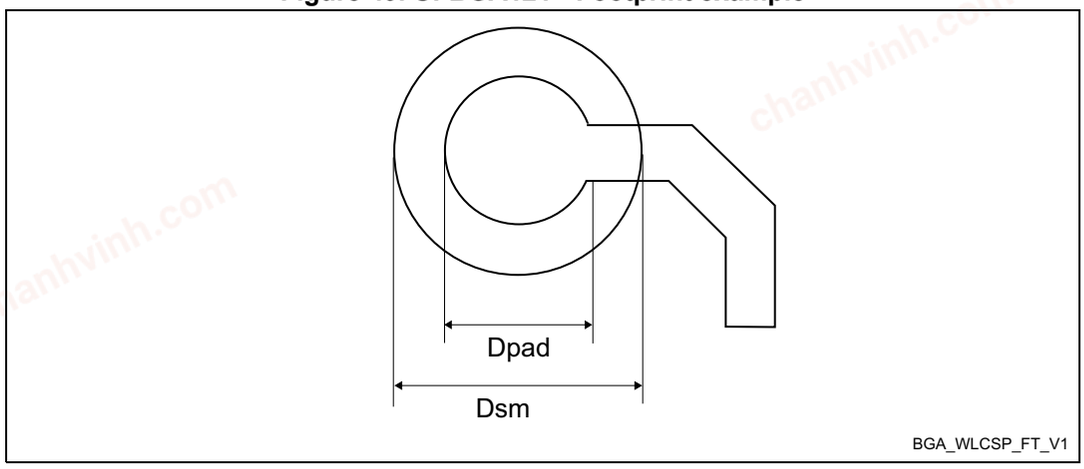


Table 106. UFBGA121 - Example of PCB design rules

Dimension	Values
Pitch	0.5 mm
Dpad	0.225 mm
Dsm	0.290 mm typ. (depends on soldermask registration tolerance)
Stencil opening	0.250 mm
Stencil thickness	0.100 mm

6.6 Thermal characteristics

The maximum chip junction temperature ($T_J$max) must never exceed the specified values.

T_J max (in Celsius degrees) can be calculated using the equation:

$$T_J \text{ max} = T_A \text{ max} + (P_D \text{ max} \times \Theta_{JA})$$

where:

- T_A max is the maximum ambient temperature in °C
- Θ_{JA} is the package junction-to-ambient thermal resistance, in °C/W
- P_D max is the sum of P_{INT} max and $P_{I/O}$ max (P_D max = P_{INT} max + $P_{I/O}$ max)
- P_{INT} max is the product of I_{DD} and V_{DD}, expressed in Watt (this is the maximum chip internal power)

$P_{I/O}$ max represents the maximum power dissipation on output pins:

- $P_{I/O}$ max = $\Sigma (V_{OL} \times I_{OL}) + \Sigma ((V_{DD} - V_{OH}) \times I_{OH})$

taking into account the actual V_{OL} / I_{OL} and V_{OH} / I_{OH} of the I/Os at low and high level in the application.

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Table 107. Package thermal characteristics

Symbol	Parameter	Package	Value	Unit
Θ_{JA}	Thermal resistance junction-ambient	UFQFPN48 - 7 mm x 7 mm	28.2	°C/W
		VFQFPN68 - 8 mm x 8 mm	24.9	
		Thin WLCSP88 - 3.78 mm x 3.46 mm	46.3	
		UFBGA121 - 6 mm x 6 mm	40.8	
Θ_{JB}	Thermal resistance junction-board	UFQFPN48 - 7 mm x 7 mm	12.4	
		VFQFPN68 - 8 mm x 8 mm	10.2	
		Thin WLCSP88 - 3.78 mm x 3.46 mm	23.5	
		UFBGA121 - 6 mm x 6 mm	25.0	
Θ_{JC}	Thermal resistance junction-case	UFQFPN48 - 7 mm x 7 mm	8.8	
		VFQFPN68 - 8 mm x 8 mm	12.3	
		Thin WLCSP88 - 3.78 mm x 3.46 mm	2.5	
		UFBGA121 - 6 mm x 6 mm	10.6	

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7 Ordering information

Example: STM32 WB A65 C I U 6 TR

Device family

STM32 = Arm® based 32-bit microcontroller

Product type

WB = Wireless Bluetooth®

Device subfamily

A62 = Die A6, reduced set of features
A63 = Die A6, crossover SMPS
A64 = Die A6, full set of features LDO
A65 = Die A6, full set of features SMPS

Pin count

C = 48 pins
R = 68 pins
M = 88 pins
P = 121 pins

Flash memory size

I = 2 Mbytes

G = 1 Mbyte

Package

U = UFQFPN
V = VFQFPN
F = Thin WLCSP
I = UFBGA

Temperature range

6 = Industrial temperature range, -40 to 85 °C (105 °C junction)
7 = Industrial temperature range, -40 to 105 °C (125 °C junction)

Packing

TR = tape and reel

xxx = programmed parts

For a list of available options, or for further information on any aspect of this device, contact your nearest ST sales office.

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8 Important security notice

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9 Revision history

Table 108. Document revision history

Date	Revision	Changes
13-Dec-2024	1	Initial release.

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