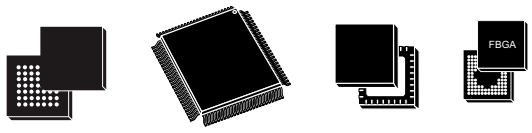
STM32F401xD STM32F401xE

ARM® Cortex®-M4 32b MCU+FPU, 105 DMIPS, 512KB Flash/96KB RAM, 11 TIMs, 1 ADC, 11 comm. interfaces

Datasheet - production data

Features

- Core: ARM® 32-bit Cortex®-M4 CPU with FPU, Adaptive real-time accelerator (ART Accelerator™) allowing 0-wait state execution from Flash memory, frequency up to 84 MHz, memory protection unit, 105 DMIPS/1.25 DMIPS/MHz (Dhrystone 2.1), and DSP instructions
- Memories
  - up to 512 Kbytes of Flash memory
  - up to 96 Kbytes of SRAM
- Clock, reset and supply management
  - 1.7 V to 3.6 V application supply and I/Os
  - POR, PDR, PVD and BOR
  - 4-to-26 MHz crystal oscillator
  - Internal 16 MHz factory-trimmed RC
  - 32 kHz oscillator for RTC with calibration
  - Internal 32 kHz RC with calibration
- Power consumption
  - Run: 146 µA/MHz (peripheral off)
  - Stop (Flash in Stop mode, fast wakeup time): 42 µA Typ @ 25C; 65 µA max @25 °C
  - Stop (Flash in Deep power down mode, fast wakeup time): down to 10 µA @ 25 °C; 30 µA max @25 °C
  - Standby: 2.4 µA @25 °C / 1.7 V without RTC; 12 µA @85 °C @1.7 V
  - V_{BAT} supply for RTC: 1 µA @25 °C
- 1×12-bit, 2.4 MSPS A/D converter: up to 16 channels
- General-purpose DMA: 16-stream DMA controllers with FIFOs and burst support
- Up to 11 timers: up to six 16-bit, two 32-bit timers up to 84 MHz, each with up to four IC/OC/PWM or pulse counter and quadrature (incremental) encoder input, two watchdog timers (independent and window) and a SysTick timer



WLCSP49 (3.06 x 3.06 mm) | LQFP100 (14 × 14 mm) LQFP64 (10 × 10 mm) | UFQFPN48 (7 × 7 mm) | UFBGA100 (7 × 7 mm)

- Debug mode
  - Serial wire debug (SWD) & JTAG interfaces
  - Cortex®-M4 Embedded Trace Macrocell™
- Up to 81 I/O ports with interrupt capability
  - Up to 78 fast I/Os up to 42 MHz
  - All I/O ports are 5 V-tolerant
- Up to 12 communication interfaces
  - Up to 3 x I^2C interfaces (SMBus/PMBus)
  - Up to 3 USARTs (2 x 10.5 Mbit/s, 1 x 5.25 Mbit/s), ISO 7816 interface, LIN, IrDA, modem control)
  - Up to 4 SPIs (up to 42Mbit/s at f_{CPU} = 84 MHz), SPI2 and SPI3 with muxed full-duplex I^2S to achieve audio class accuracy via internal audio PLL or external clock
  - SDIO interface
  - Advanced connectivity: USB 2.0 full-speed device/host/OTG controller with on-chip PHY
- CRC calculation unit
- 96-bit unique ID
- RTC: subsecond accuracy, hardware calendar
- All packages (WLCSP49, LQFP64/100, UFQFPN48, UFBGA100) are ECOPACK®2

Table 1. Device summary

Reference	Part number
STM32F401xD	STM32F401CD, STM32F401RD, STM32F401VD
STM32F401xE	STM32F401CE, STM32F401RE, STM32F401VE

This is information on a product in full production. www.st.com

Contents

1 **Introduction** 9

2 **Description** 10

2.1 Compatibility with STM32F4 series 12

3 **Functional overview** 15

3.1 ARM® Cortex®-M4 with FPU core with embedded Flash and SRAM . . . 15

3.2 Adaptive real-time memory accelerator (ART Accelerator™) 15

3.3 Memory protection unit 15

3.4 Embedded Flash memory 16

3.5 CRC (cyclic redundancy check) calculation unit 16

3.6 Embedded SRAM 16

3.7 Multi-AHB bus matrix 16

3.8 DMA controller (DMA) 17

3.9 Nested vectored interrupt controller (NVIC) 18

3.10 External interrupt/event controller (EXTI) 18

3.11 Clocks and startup 18

3.12 Boot modes 19

3.13 Power supply schemes 19

3.14 Power supply supervisor 20

3.14.1 Internal reset ON 20

3.14.2 Internal reset OFF 20

3.15 Voltage regulator 21

3.15.1 Regulator ON 21

3.15.2 Regulator OFF 22

3.15.3 Regulator ON/OFF and internal power supply supervisor availability . . 25

3.16 Real-time clock (RTC) and backup registers 25

3.17 Low-power modes 26

3.18 V_{BAT} operation 26

3.19 Timers and watchdogs 27

3.19.1 Advanced-control timers (TIM1) 27

3.19.2 General-purpose timers (TIMx) 28

3.19.3 Independent watchdog 28
3.19.4 Window watchdog 28
3.19.5 SysTick timer 29
3.20 Inter-integrated circuit interface (I2C) 29
3.21 Universal synchronous/asynchronous receiver transmitters (USART) . . 29
3.22 Serial peripheral interface (SPI) 30
3.23 Inter-integrated sound (I^2S) 30
3.24 Audio PLL (PLLI2S) 30
3.25 Secure digital input/output interface (SDIO) 31
3.26 Universal serial bus on-the-go full-speed (OTG_FS) 31
3.27 General-purpose input/outputs (GPIOs) 31
3.28 Analog-to-digital converter (ADC) 31
3.29 Temperature sensor 32
3.30 Serial wire JTAG debug port (SWJ-DP) 32
3.31 Embedded Trace Macrocell™ 32

4 Pinouts and pin description 33

5 Memory mapping 51

6 Electrical characteristics 55
6.1 Parameter conditions 55
6.1.1 Minimum and maximum values 55
6.1.2 Typical values 55
6.1.3 Typical curves 55
6.1.4 Loading capacitor 55
6.1.5 Pin input voltage 56
6.1.6 Power supply scheme 57
6.1.7 Current consumption measurement 58
6.2 Absolute maximum ratings 58
6.3 Operating conditions 60
6.3.1 General operating conditions 60
6.3.2 VCAP1/VCAP2 external capacitors 62
6.3.3 Operating conditions at power-up/power-down (regulator ON) 63
6.3.4 Operating conditions at power-up / power-down (regulator OFF) 63
6.3.5 Embedded reset and power control block characteristics 64

6.3.6 Supply current characteristics . . . 65
6.3.7 Wakeup time from low-power modes . . . 75
6.3.8 External clock source characteristics . . . 76
6.3.9 Internal clock source characteristics . . . 80
6.3.10 PLL characteristics . . . 82
6.3.11 PLL spread spectrum clock generation (SSCG) characteristics . . . 84
6.3.12 Memory characteristics . . . 85
6.3.13 EMC characteristics . . . 87
6.3.14 Absolute maximum ratings (electrical sensitivity) . . . 89
6.3.15 I/O current injection characteristics . . . 90
6.3.16 I/O port characteristics . . . 91
6.3.17 NRST pin characteristics . . . 96
6.3.18 TIM timer characteristics . . . 97
6.3.19 Communications interfaces . . . 98
6.3.20 12-bit ADC characteristics . . . 106
6.3.21 Temperature sensor characteristics . . . 112
6.3.22 V_{BAT} monitoring characteristics . . . 112
6.3.23 Embedded reference voltage . . . 112
6.3.24 SD/SDIO MMC card host interface (SDIO) characteristics . . . 113
6.3.25 RTC characteristics . . . 114

7 Package characteristics . . . 115
7.1 Package mechanical data . . . 115
7.1.1 WLCSP49, 3.06 x 3.06 mm, 0.4 mm pitch wafer level chip size package . . . 116
7.1.2 UFQFPN48, 7 x 7 mm, 0.5 mm pitch package . . . 119
7.1.3 LQFP64, 10 x 10 mm, 64-pin low-profile quad flat package . . . 122
7.1.4 LQFP100, 14 x 14 mm, 100-pin low-profile quad flat package . . . 125
7.1.5 UFBGA100, 7 x 7 mm, 0.5 mm pitch package . . . 128
7.2 Thermal characteristics . . . 131
7.2.1 Reference document . . . 131

8 Part numbering . . . 132

9 Revision history . . . 134

List of tables

Table 1. Device summary . . . 1
Table 2. STM32F401xD/xE features and peripheral counts . . . 11
Table 3. Regulator ON/OFF and internal power supply supervisor availability . . . 25
Table 4. Timer feature comparison . . . 27
Table 5. Comparison of I2C analog and digital filters . . . 29
Table 6. USART feature comparison . . . 30
Table 7. Legend/abbreviations used in the pinout table . . . 38
Table 8. STM32F401xD/xE pin definitions . . . 38
Table 9. Alternate function mapping . . . 45
Table 10. STM32F401xD register boundary addresses . . . 52
Table 11. Voltage characteristics . . . 58
Table 12. Current characteristics . . . 59
Table 13. Thermal characteristics . . . 59
Table 14. General operating conditions . . . 60
Table 15. Features depending on the operating power supply range . . . 61
Table 16. VCAP1/VCAP2 operating conditions . . . 62
Table 17. Operating conditions at power-up / power-down (regulator ON) . . . 63
Table 18. Operating conditions at power-up / power-down (regulator OFF) . . . 63
Table 19. Embedded reset and power control block characteristics . . . 64
Table 20. Typical and maximum current consumption, code with data processing (ART accelerator disabled) running from SRAM - V_{DD} = 1.7 V . . . 66
Table 21. Typical and maximum current consumption, code with data processing (ART accelerator disabled) running from SRAM . . . 66
Table 22. Typical and maximum current consumption in run mode, code with data processing (ART accelerator enabled except prefetch) running from Flash memory- V_{DD} = 1.7 V . . . 67
Table 23. Typical and maximum current consumption in run mode, code with data processing (ART accelerator enabled except prefetch) running from Flash memory - V_{DD} = 3.3 V . . . 67
Table 24. Typical and maximum current consumption in run mode, code with data processing (ART accelerator disabled) running from Flash memory . . . 68
Table 25. Typical and maximum current consumption in run mode, code with data processing (ART accelerator enabled with prefetch) running from Flash memory . . . 68
Table 26. Typical and maximum current consumption in Sleep mode . . . 69
Table 27. Typical and maximum current consumptions in Stop mode - V_{DD}=1.8 V . . . 69
Table 28. Typical and maximum current consumption in Stop mode - V_{DD}=3.3 V . . . 70
Table 29. Typical and maximum current consumption in Standby mode - V_{DD}=1.8 V . . . 70
Table 30. Typical and maximum current consumption in Standby mode - V_{DD}=3.3 V . . . 70
Table 31. Typical and maximum current consumptions in V_{BAT} mode . . . 71
Table 32. Switching output I/O current consumption . . . 73
Table 33. Peripheral current consumption . . . 74
Table 34. Low-power mode wakeup timings(1) . . . 75
Table 35. High-speed external user clock characteristics . . . 76
Table 36. Low-speed external user clock characteristics . . . 77
Table 37. HSE 4-26 MHz oscillator characteristics . . . 78
Table 38. LSE oscillator characteristics (f_{LSE} = 32.768 kHz) . . . 79
Table 39. HSI oscillator characteristics . . . 80
Table 40. LSI oscillator characteristics . . . 81
Table 41. Main PLL characteristics . . . 82
Table 42. PLLI2S (audio PLL) characteristics . . . 83

Table 43. SSCG parameters constraint . . . 84
Table 44. Flash memory characteristics . . . 85
Table 45. Flash memory programming . . . 86
Table 46. Flash memory programming with V_{PP} voltage . . . 86
Table 47. Flash memory endurance and data retention . . . 87
Table 48. EMS characteristics for LQFP100 package . . . 88
Table 49. EMI characteristics for WLCSP49 . . . 89
Table 50. EMI characteristics for LQFP100 . . . 89
Table 51. ESD absolute maximum ratings . . . 90
Table 52. Electrical sensitivities . . . 90
Table 53. I/O current injection susceptibility . . . 91
Table 54. I/O static characteristics . . . 91
Table 55. Output voltage characteristics . . . 94
Table 56. I/O AC characteristics . . . 94
Table 57. NRST pin characteristics . . . 96
Table 58. TIMx characteristics . . . 97
Table 59. I^2C characteristics . . . 98
Table 60. SCL frequency (f_{PCLK1}= 42 MHz, V_{DD} = V_{DD_I2C} = 3.3 V) . . . 99
Table 61. SPI dynamic characteristics . . . 100
Table 62. I^2S dynamic characteristics . . . 103
Table 63. USB OTG FS startup time . . . 105
Table 64. USB OTG FS DC electrical characteristics . . . 105
Table 65. USB OTG FS electrical characteristics . . . 106
Table 66. ADC characteristics . . . 106
Table 67. ADC accuracy at f_{ADC} = 18 MHz . . . 108
Table 68. ADC accuracy at f_{ADC} = 30 MHz . . . 108
Table 69. ADC accuracy at f_{ADC} = 36 MHz . . . 108
Table 70. ADC dynamic accuracy at f_{ADC} = 18 MHz - limited test conditions . . . 109
Table 71. ADC dynamic accuracy at f_{ADC} = 36 MHz - limited test conditions . . . 109
Table 72. Temperature sensor characteristics . . . 112
Table 73. Temperature sensor calibration values . . . 112
Table 74. V_{BAT} monitoring characteristics . . . 112
Table 75. Embedded internal reference voltage . . . 112
Table 76. Internal reference voltage calibration values . . . 113
Table 77. Dynamic characteristics: SD / MMC characteristics . . . 114
Table 78. RTC characteristics . . . 114
Table 79. STM32F401xCE WLCSP49 wafer level chip size package mechanical data . . . 116
Table 80. WLCSP49 recommended PCB design rules (0.4 mm pitch) . . . 118
Table 81. UFQFPN48, 7 x 7 mm, 0.5 mm pitch, package mechanical data . . . 119
Table 82. LQFP64, 10 x 10 mm, 64-pin low-profile quad flat package mechanical data . . . 123
Table 83. LQPF100, 14 x 14 mm, 100-pin low-profile quad flat package mechanical data . . . 126
Table 84. UFBGA100, 7 x 7 mm, 0.50 mm pitch, ultra fine pitch ball grid array package mechanical data . . . 128
Table 85. Package thermal characteristics . . . 131
Table 86. Ordering information scheme . . . 132
Table 87. Device order codes . . . 133
Table 88. Document revision history . . . 134

List of figures

Figure 1. Compatible board design for LQFP100 package . . . 12
Figure 2. Compatible board design for LQFP64 package . . . 13
Figure 3. STM32F401xD/xE block diagram . . . 14
Figure 4. Multi-AHB matrix . . . 17
Figure 5. Power supply supervisor interconnection with internal reset OFF . . . 20
Figure 6. PDR_ON control with internal reset OFF . . . 21
Figure 7. Regulator OFF . . . 23
Figure 8. Startup in regulator OFF: slow V_{DD} slope - power-down reset risen after V_{CAP_1}/V_{CAP_2} stabilization . . . 24
Figure 9. Startup in regulator OFF mode: fast V_{DD} slope - power-down reset risen before V_{CAP_1}/V_{CAP_2} stabilization . . . 24
Figure 10. STM32F401xD/xE WLCSP49 pinout . . . 33
Figure 11. STM32F401xD/xE UFQFPN48 pinout . . . 34
Figure 12. STM32F401xD/xE LQFP64 pinout . . . 35
Figure 13. STM32F401xD/xE LQFP100 pinout . . . 36
Figure 14. STM32F401xD/xE UFBGA100 pinout . . . 37
Figure 15. Memory map . . . 51
Figure 16. Pin loading conditions . . . 55
Figure 17. Input voltage measurement . . . 56
Figure 18. Power supply scheme . . . 57
Figure 19. Current consumption measurement scheme . . . 58
Figure 20. External capacitor C_{EXT} . . . 62
Figure 21. Typical V_{BAT} current consumption (LSE and RTC ON) . . . 71
Figure 22. High-speed external clock source AC timing diagram . . . 77
Figure 23. Low-speed external clock source AC timing diagram . . . 78
Figure 24. Typical application with an 8 MHz crystal . . . 79
Figure 25. Typical application with a 32.768 kHz crystal . . . 80
Figure 26. ACC_{HSI} versus temperature . . . 81
Figure 27. ACC_{LSI} versus temperature . . . 82
Figure 28. PLL output clock waveforms in center spread mode . . . 85
Figure 29. PLL output clock waveforms in down spread mode . . . 85
Figure 30. FT I/O input characteristics . . . 93
Figure 31. I/O AC characteristics definition . . . 96
Figure 32. Recommended NRST pin protection . . . 97
Figure 33. I^2C bus AC waveforms and measurement circuit . . . 99
Figure 34. SPI timing diagram - slave mode and CPHA = 0 . . . 101
Figure 35. SPI timing diagram - slave mode and CPHA = 1(1) . . . 101
Figure 36. SPI timing diagram - master mode(1) . . . 102
Figure 37. I^2S slave timing diagram (Philips protocol)(1) . . . 104
Figure 38. I^2S master timing diagram (Philips protocol)(1) . . . 104
Figure 39. USB OTG FS timings: definition of data signal rise and fall time . . . 106
Figure 40. ADC accuracy characteristics . . . 110
Figure 41. Typical connection diagram using the ADC . . . 110
Figure 42. Power supply and reference decoupling (V_{REF+} not connected to V_{DDA}) . . . 111
Figure 43. Power supply and reference decoupling (V_{REF+} connected to V_{DDA}) . . . 111
Figure 44. SDIO high-speed mode . . . 113
Figure 45. SD default mode . . . 114
Figure 46. WLCSP49 wafer level chip size package outline . . . 116

Figure 47. WLCSP49 0.4 mm pitch wafer level chip size recommended footprint . . . 117
Figure 48. Example of WLCSP49 marking (top view) . . . 118
Figure 49. UFQFPN48, 7 x 7 mm, 0.5 mm pitch, package outline. . . . 119
Figure 50. UFQFPN48 recommended footprint . . . 120
Figure 51. Example of UFQFPN48 marking (top view) . . . 121
Figure 52. LQFP64, 10 x 10 mm, 64-pin low-profile quad flat package outline . . . 122
Figure 53. LQFP64 recommended footprint . . . 123
Figure 54. Example of LQFP64 marking (top view) . . . 124
Figure 55. LQFP100, 14 x 14 mm, 100-pin low-profile quad flat package outline . . . 125
Figure 56. LQFP100 recommended footprint . . . 127
Figure 57. Example of LQPF100 marking (top view) . . . 127
Figure 58. UFBGA100, 7 x 7 mm, 0.50 mm pitch, ultra fine pitch ball grid array package outline. . . . 128
Figure 59. Recommended PCB design rules for pads (0.5 mm-pitch BGA) . . . 129
Figure 60. Example of UFBGA100 marking (top view) . . . 130

1 Introduction

This datasheet provides the description of the STM32F401xD/xE line of microcontrollers.

The STM32F401xD/xE datasheet should be read in conjunction with RM0368 reference manual which is available from the STMicroelectronics website *www.st.com*. It includes all information concerning Flash memory programming.

For information on the Cortex®-M4 core, please refer to the Cortex®-M4 programming manual (PM0214) available from *www.st.com*.

2 Description

The STM32F401xD/xE devices are based on the high-performance ARM® Cortex® -M4 32-bit RISC core operating at a frequency of up to 84 MHz. Its Cortex®-M4 core features a Floating point unit (FPU) single precision which supports all ARM single-precision data-processing instructions and data types. It also implements a full set of DSP instructions and a memory protection unit (MPU) which enhances application security.

The STM32F401xD/xE incorporate high-speed embedded memories (512 Kbytes of Flash memory, 96 Kbytes of SRAM), and an extensive range of enhanced I/Os and peripherals connected to two APB buses, two AHB buses and a 32-bit multi-AHB bus matrix.

All devices offer one 12-bit ADC, a low-power RTC, six general-purpose 16-bit timers including one PWM timer for motor control, two general-purpose 32-bit timers. They also feature standard and advanced communication interfaces.

- Up to three I^2Cs
- Up to four SPIs
- Two full duplex I^2Ss. To achieve audio class accuracy, the I^2S peripherals can be clocked via a dedicated internal audio PLL or via an external clock to allow synchronization.
- Three USARTs
- SDIO interface
- USB 2.0 OTG full speed interface

Refer to for the peripherals available for each part number.

The STM32F401xD/xE operate in the –40 to +105 °C temperature range from a 1.7 (PDR OFF) to 3.6 V power supply. A comprehensive set of power-saving mode allows the design of low-power applications.

These features make the STM32F401xD/xE microcontrollers suitable for a wide range of applications:

- Motor drive and application control
- Medical equipment
- Industrial applications: PLC, inverters, circuit breakers
- Printers, and scanners
- Alarm systems, video intercom, and HVAC
- Home audio appliances
- Mobile phone sensor hub

Figure 3 shows the general block diagram of the devices.

Table 2. STM32F401xD/xE features and peripheral counts

Peripherals		STM32F401xD			STM32F401xE		
Flash memory in Kbytes		384			512		
SRAM in Kbytes	System	96					
Timers	General-purpose	7					
	Advanced-control	1					
Communication interfaces	SPI/ I^2S	3/2 (full duplex)		4/2 (full duplex)	3/2 (full duplex)		4/2 (full duplex)
	I^2C	3					
	USART	3					
	SDIO	-	1		-	1	
USB OTG FS		1					
GPIOs		36	50	81	36	50	81
12-bit ADC		1					
Number of channels		10	16		10	16	
Maximum CPU frequency		84 MHz					
Operating voltage		1.7 to 3.6 V					
Operating temperatures		Ambient temperatures: –40 to +85 °C/–40 to +105 °C					
		Junction temperature: –40 to + 125 °C					
Package		WLCSP49 UFQFPN48	LQFP64	UFBGA100 LQFP100	WLCSP49 UFQFPN48	LQFP64	UFBGA100 LQFP100

2.1 Compatibility with STM32F4 series

The STM32F401xD/xE are fully software and feature compatible with the STM32F4 series (STM32F42x, STM32F43x, STM32F41x, STM32F405 and STM32F407)

The STM32F401xD/xE can be used as drop-in replacement of the other STM32F4 products but some slight changes have to be done on the PCB board.

Figure 1. Compatible board design for LQFP100 package

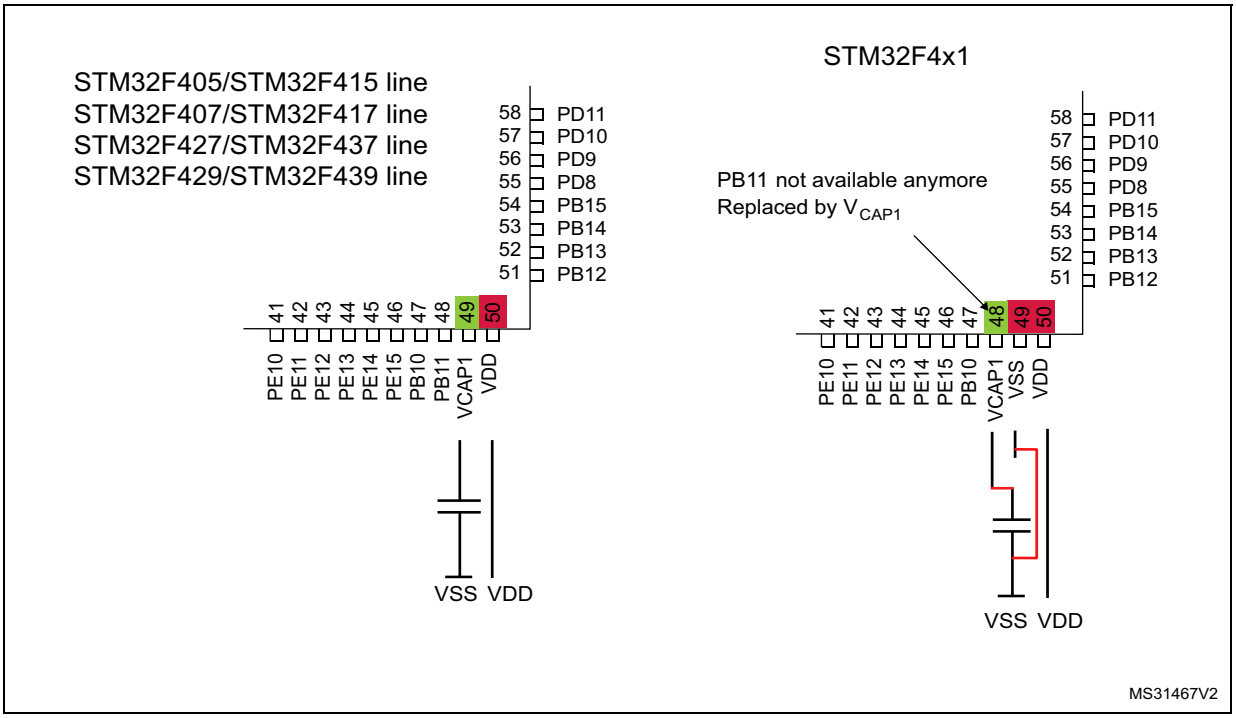


Figure 2. Compatible board design for LQFP64 package

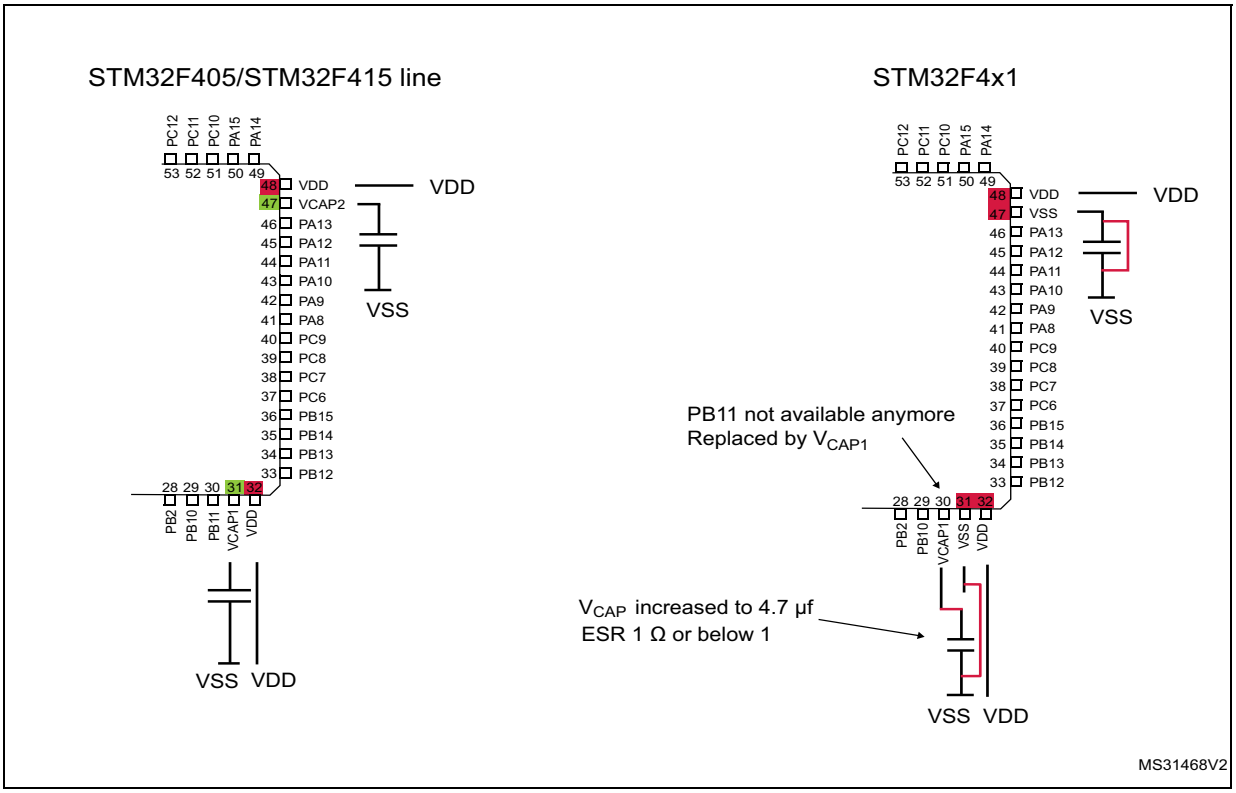
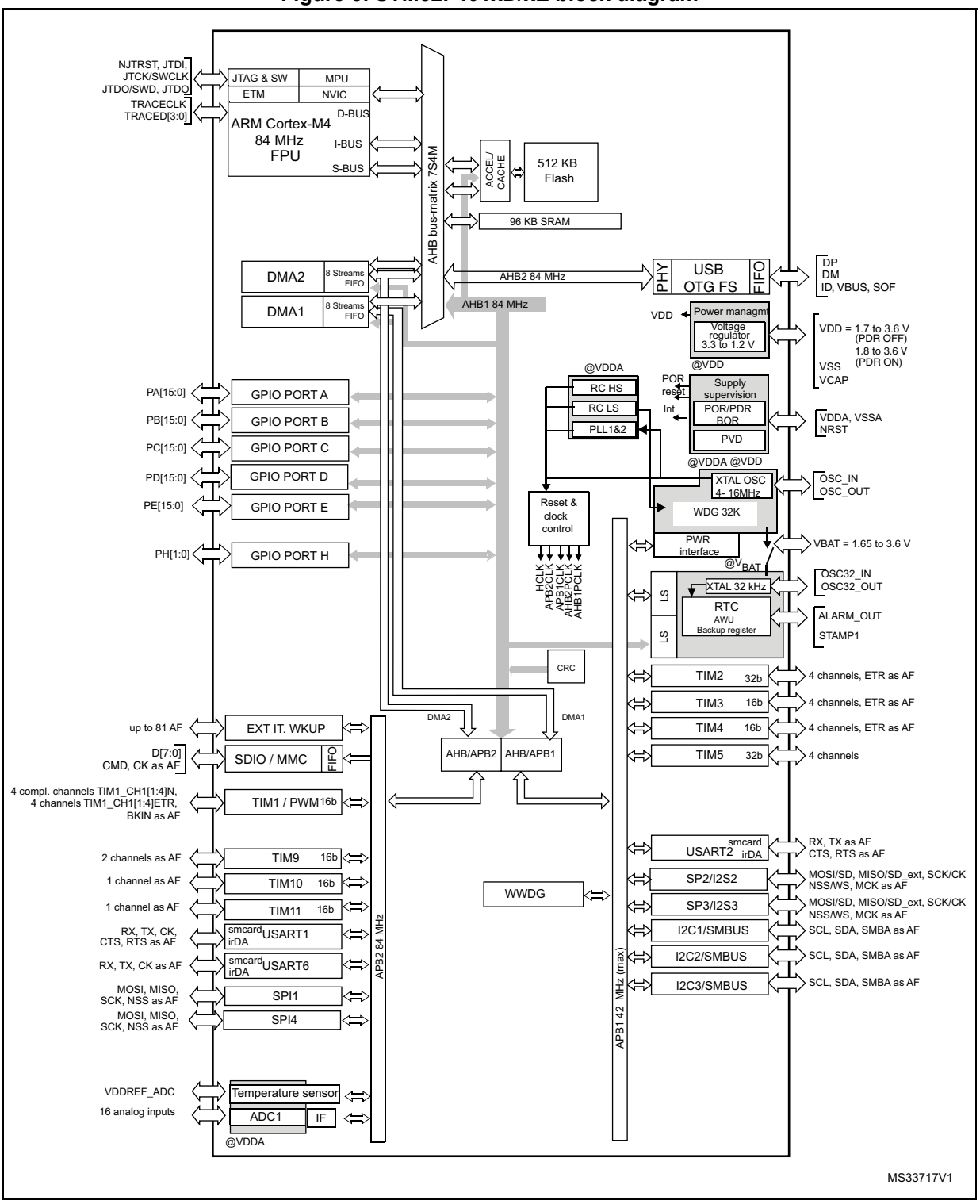


Figure 3. STM32F401xD/xE block diagram



1. The timers connected to APB2 are clocked from TIMxCLK up to 84 MHz, while the timers connected to APB1 are clocked from TIMxCLK up to 42 MHz.

3 Functional overview

3.1 ARM® Cortex®-M4 with FPU core with embedded Flash and SRAM

The ARM® Cortex®-M4 with FPU processor is the latest generation of ARM processors for embedded systems. It was developed to provide a low-cost platform that meets the needs of MCU implementation, with a reduced pin count and low-power consumption, while delivering outstanding computational performance and an advanced response to interrupts.

The ARM® Cortex®-M4 with FPU 32-bit RISC processor features exceptional code-efficiency, delivering the high-performance expected from an ARM core in the memory size usually associated with 8- and 16-bit devices. The processor supports a set of DSP instructions which allow efficient signal processing and complex algorithm execution. Its single precision FPU (floating point unit) speeds up software development by using metalanguage development tools, while avoiding saturation.

The STM32F401xD/xE devices are compatible with all ARM tools and software.

Figure 3 shows the general block diagram of the STM32F401xD/xE.

Note: Cortex®-M4 with FPU is binary compatible with Cortex®-M3.

3.2 Adaptive real-time memory accelerator (ART Accelerator™)

The ART Accelerator™ is a memory accelerator which is optimized for STM32 industry-standard ARM® Cortex®-M4 with FPU processors. It balances the inherent performance advantage of the ARM® Cortex®-M4 with FPU over Flash memory technologies, which normally requires the processor to wait for the Flash memory at higher frequencies.

To release the processor full 105 DMIPS performance at this frequency, the accelerator implements an instruction prefetch queue and branch cache, which increases program execution speed from the 128-bit Flash memory. Based on CoreMark benchmark, the performance achieved thanks to the ART accelerator is equivalent to 0 wait state program execution from Flash memory at a CPU frequency up to 84 MHz.

3.3 Memory protection unit

The memory protection unit (MPU) is used to manage the CPU accesses to memory to prevent one task to accidentally corrupt the memory or resources used by any other active task. This memory area is organized into up to 8 protected areas that can in turn be divided up into 8 subareas. The protection area sizes are between 32 bytes and the whole 4 gigabytes of addressable memory.

The MPU is especially helpful for applications where some critical or certified code has to 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 that is 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 Embedded Flash memory

The devices embed 512 Kbytes of Flash memory available for storing programs and data.

3.5 CRC (cyclic redundancy check) calculation unit

The CRC (cyclic redundancy check) calculation unit is used to get a CRC code from a 32-bit data word and a fixed generator polynomial.

Among other applications, 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 means of verifying the Flash memory integrity. The CRC calculation unit helps compute a software signature during runtime, to be compared with a reference signature generated at link-time and stored at a given memory location.

3.6 Embedded SRAM

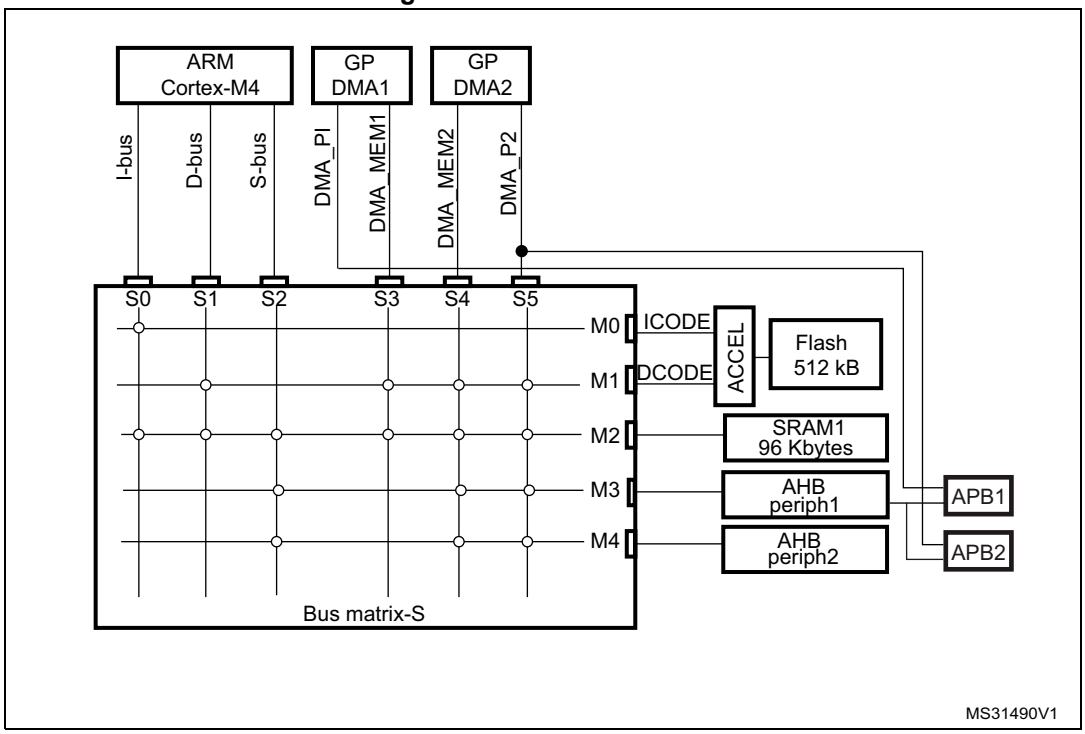
All devices embed:

- 96 Kbytes of system SRAM which can be accessed (read/write) at CPU clock speed with 0 wait states

3.7 Multi-AHB bus matrix

The 32-bit multi-AHB bus matrix interconnects all the masters (CPU, DMAs) and the slaves (Flash memory, RAM, AHB and APB peripherals) and ensures a seamless and efficient operation even when several high-speed peripherals work simultaneously.

Figure 4. Multi-AHB matrix



3.8 DMA controller (DMA)

The devices feature two general-purpose dual-port DMAs (DMA1 and DMA2) with 8 streams each. They are able to manage memory-to-memory, peripheral-to-memory and memory-to-peripheral transfers. They feature dedicated FIFOs for APB/AHB peripherals, support burst transfer and are designed to provide the maximum peripheral bandwidth (AHB/APB).

The two DMA controllers support circular buffer management, so that no specific code is needed when the controller reaches the end of the buffer. The two DMA controllers also have a double buffering feature, which automates the use and switching of two memory buffers without requiring any special code.

Each stream is connected to dedicated hardware DMA requests, with support for software trigger on each stream. Configuration is made by software and transfer sizes between source and destination are independent.

The DMA can be used with the main peripherals:

- SPI and I^2S
- I^2C
- USART
- General-purpose, basic and advanced-control timers TIMx
- SD/SDIO/MMC host interface
- ADC

3.9 Nested vectored interrupt controller (NVIC)

The devices embed a nested vectored interrupt controller able to manage 16 priority levels, and handle up to 62 maskable interrupt channels plus the 16 interrupt lines of the Cortex®-M4 with FPU.

- Closely coupled NVIC gives low-latency interrupt processing
- Interrupt entry vector table address passed directly to the core
- Allows early processing of interrupts
- Processing of late arriving, higher-priority interrupts
- Support tail chaining
- Processor state automatically saved
- Interrupt entry restored on interrupt exit with no instruction overhead

This hardware block provides flexible interrupt management features with minimum interrupt latency.

3.10 External interrupt/event controller (EXTI)

The external interrupt/event controller consists of 21 edge-detector lines used to generate interrupt/event requests. Each line can be independently configured to select the trigger event (rising edge, falling edge, both) and can be masked independently. A pending register maintains the status of the interrupt requests. The EXTI can detect an external line with a pulse width shorter than the Internal APB2 clock period. Up to 81 GPIOs can be connected to the 16 external interrupt lines.

3.11 Clocks and startup

On reset the 16 MHz internal RC oscillator is selected as the default CPU clock. The 16 MHz internal RC oscillator is factory-trimmed to offer 1% accuracy at 25 °C. The application can then select as system clock either the RC oscillator or an external 4-26 MHz clock source. This clock can be monitored for failure. If a failure is detected, the system automatically switches back to the internal RC oscillator and a software interrupt is generated (if enabled). This clock source is input to a PLL thus allowing to increase the frequency up to 84 MHz. Similarly, full interrupt management of the PLL clock entry is available when necessary (for example if an indirectly used external oscillator fails).

Several prescalers allow the configuration of the two AHB buses, the high-speed APB (APB2) and the low-speed APB (APB1) domains. The maximum frequency of the two AHB buses is 84 MHz while the maximum frequency of the high-speed APB domains is 84 MHz. The maximum allowed frequency of the low-speed APB domain is 42 MHz.

The devices embed a dedicated PLL (PLLI2S) which allows to achieve audio class performance. In this case, the I^2S master clock can generate all standard sampling frequencies from 8 kHz to 192 kHz.

3.12 Boot modes

At startup, boot pins are used to select one out of three boot options:

- Boot from user Flash
- Boot from system memory
- Boot from embedded SRAM

The boot loader is located in system memory. It is used to reprogram the Flash memory by using either USART1(PA9/10), USART2(PD5/6), USB OTG FS in device mode (PA11/12) through DFU (device firmware upgrade), I2C1(PB6/7), I2C2(PB10/3), I2C3(PA8/PB4), SPI1(PA4/5/6/7), SPI2(PB12/13/14/15) or SPI3(PA15, PC10/11/12).

For more detailed information on the bootloader, refer to Application Note: AN2606, *STM32™ microcontroller system memory boot mode*.

3.13 Power supply schemes

- V_{DD} = 1.7 to 3.6 V: external power supply for I/Os with the internal supervisor (POR/PDR) disabled, provided externally through V_{DD} pins. Requires the use of an external power supply supervisor connected to the VDD and PDR_ON pins.
- V_{DD} = 1.8 to 3.6 V: external power supply for I/Os and the internal regulator (when enabled), provided externally through V_{DD} pins.
- V_{SSA}, V_{DDA} = 1.7 to 3.6 V: external analog power supplies for ADC, Reset blocks, RCs and PLL. V_{DDA} and V_{SSA} must be connected to V_{DD} and V_{SS}, respectively, with decoupling technique.
- V_{BAT} = 1.65 to 3.6 V: power supply for RTC, external clock 32 kHz oscillator and backup registers (through power switch) when V_{DD} is not present.

Refer to *Figure 18: Power supply scheme* for more details.

3.14 Power supply supervisor

3.14.1 Internal reset ON

This feature is available for V_{DD} operating voltage range 1.8 V to 3.6 V.

The internal power supply supervisor is enabled by holding PDR_ON high.

The device has an integrated power-on reset (POR) / power-down reset (PDR) circuitry coupled with a Brownout reset (BOR) circuitry. At power-on, POR is always active, and ensures proper operation starting from 1.8 V. After the 1.8 V POR threshold level is reached, the option byte loading process starts, either to confirm or modify default thresholds, or to disable BOR permanently. Three BOR thresholds are available through option bytes.

The device remains in reset mode when V_{DD} is below a specified threshold, $V_{POR/PDR}$ or V_{BOR}, without the need for an external reset circuit.

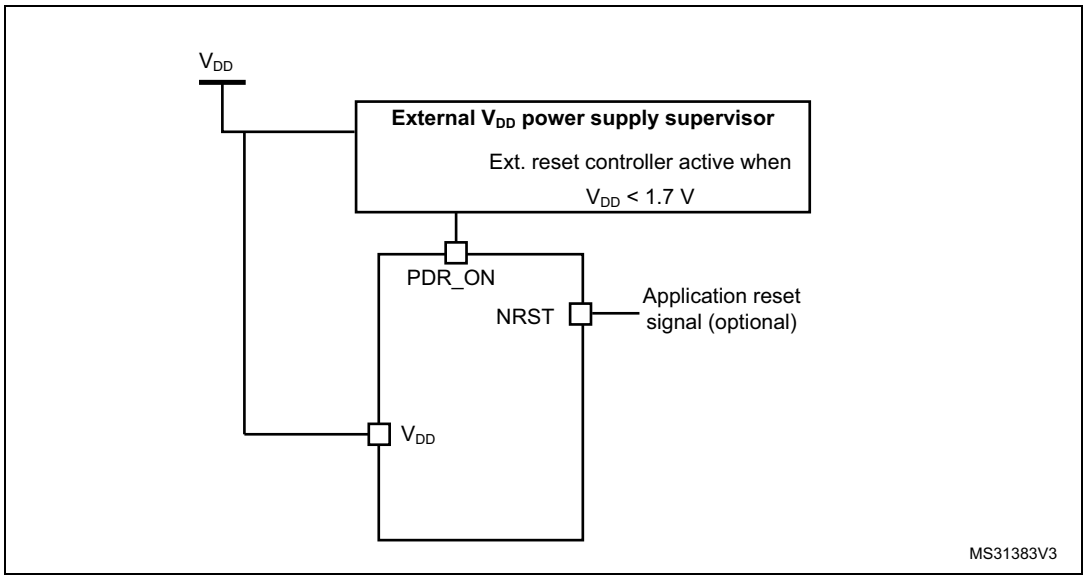
The device also features an embedded programmable voltage detector (PVD) that monitors the V_{DD}/V_{DDA} power supply and compares it to the V_{PVD} threshold. An interrupt can be generated when V_{DD}/V_{DDA} drops below the V_{PVD} threshold and/or when V_{DD}/V_{DDA} is higher than the V_{PVD} threshold. 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.

3.14.2 Internal reset OFF

This feature is available only on packages featuring the PDR_ON pin. The internal power-on reset (POR) / power-down reset (PDR) circuitry is disabled by setting the PDR_ON pin to low.

An external power supply supervisor should monitor V_{DD} and should maintain the device in reset mode as long as V_{DD} is below a specified threshold. PDR_ON should be connected to this external power supply supervisor. Refer to *Figure 5: Power supply supervisor interconnection with internal reset OFF*.

Figure 5. Power supply supervisor interconnection with internal reset OFF(1)



1. The PRD_ON pin is only available in the WLCSP49 and UFBGA100 packages.

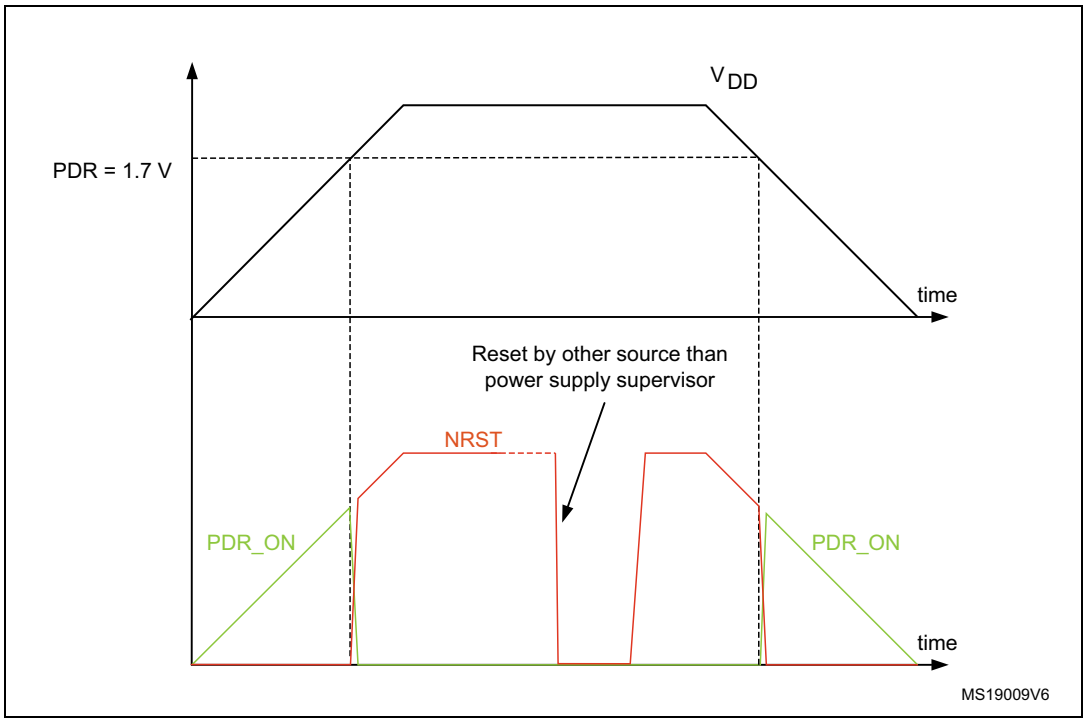
The V_{DD} specified threshold, below which the device must be maintained under reset, is 1.7 V (see *Figure 6*).

A comprehensive set of power-saving mode allows to design low-power applications.

When the internal reset is OFF, the following integrated features are no longer supported:

- The integrated power-on reset (POR) / power-down reset (PDR) circuitry is disabled.
- The brownout reset (BOR) circuitry must be disabled.
- The embedded programmable voltage detector (PVD) is disabled.
- V_{BAT} functionality is no more available and VBAT pin should be connected to V_{DD}.

Figure 6. PDR_ON control with internal reset OFF



3.15 Voltage regulator

The regulator has four operating modes:

- Regulator ON
  - Main regulator mode (MR)
  - Low power regulator (LPR)
  - Power-down
- Regulator OFF

3.15.1 Regulator ON

On packages embedding the BYPASS_REG pin, the regulator is enabled by holding BYPASS_REG low. On all other packages, the regulator is always enabled.

There are three power modes configured by software when the regulator is ON:

- MR is used in the nominal regulation mode (With different voltage scaling in Run)

  In Main regulator mode (MR mode), different voltage scaling are provided to reach the best compromise between maximum frequency and dynamic power consumption.
- LPR is used in the Stop modes

  The LP regulator mode is configured by software when entering Stop mode.
- Power-down is used in Standby mode.

  The Power-down mode is activated only when entering in Standby mode. The regulator output is in high impedance and the kernel circuitry is powered down, inducing zero consumption. The contents of the registers and SRAM are lost.

Depending on the package, one or two external ceramic capacitors should be connected on the V_{CAP_1} and V_{CAP_2} pins. The V_{CAP_2} pin is only available for the LQFP100 and UFBGA100 packages.

All packages have the regulator ON feature.

3.15.2 Regulator OFF

The Regulator OFF is available only on the UFBGA100, which features the BYPASS_REG pin. The regulator is disabled by holding BYPASS_REG high. The regulator OFF mode allows to supply externally a V12 voltage source through V_{CAP_1} and V_{CAP_2} pins.

Since the internal voltage scaling is not managed internally, the external voltage value must be aligned with the targeted maximum frequency. Refer to *Table 14: General operating conditions*.

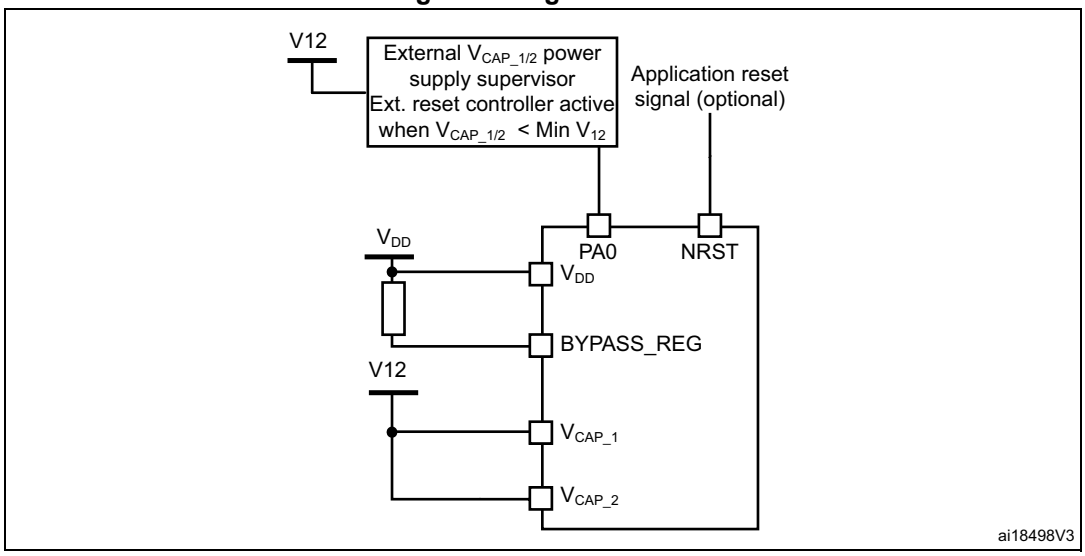
The two 2.2 µF V_{CAP} ceramic capacitors should be replaced by two 100 nF decoupling capacitors. Refer to *Figure 18: Power supply scheme*.

When the regulator is OFF, there is no more internal monitoring on V12. An external power supply supervisor should be used to monitor the V12 of the logic power domain. PA0 pin should be used for this purpose, and act as power-on reset on V12 power domain.

In regulator OFF mode, the following features are no more supported:

- PA0 cannot be used as a GPIO pin since it allows to reset a part of the V12 logic power domain which is not reset by the NRST pin.
- As long as PA0 is kept low, the debug mode cannot be used under power-on reset. As a consequence, PA0 and NRST pins must be managed separately if the debug connection under reset or pre-reset is required.

Figure 7. Regulator OFF

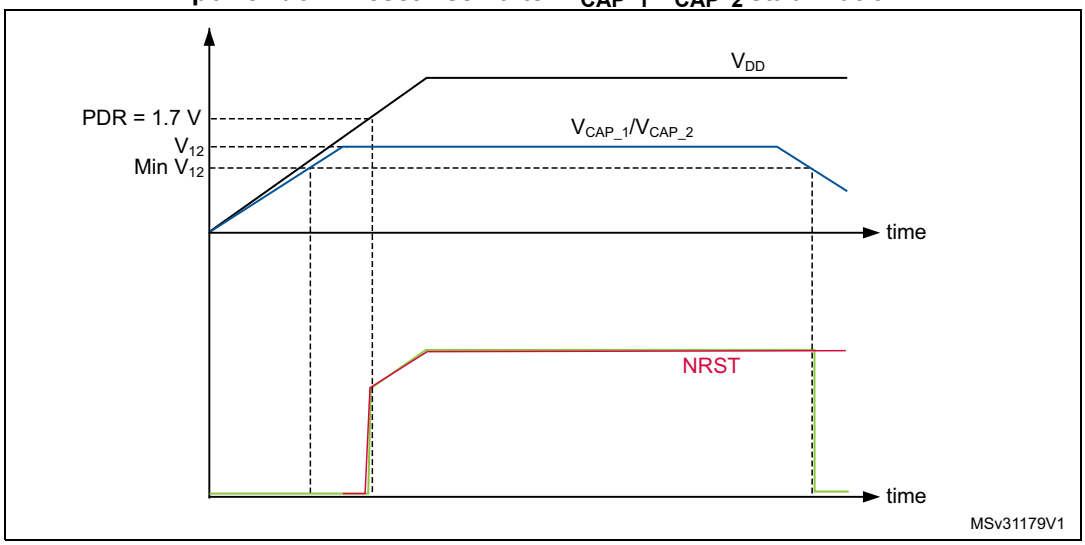


The following conditions must be respected:

- V_{DD} should always be higher than V_{CAP_1} and V_{CAP_2} to avoid current injection between power domains.
- If the time for V_{CAP_1} and V_{CAP_2} to reach V_{12} minimum value is faster than the time for V_{DD} to reach 1.7 V, then PA0 should be kept low to cover both conditions: until V_{CAP_1} and V_{CAP_2} reach V_{12} minimum value and until V_{DD} reaches 1.7 V (see *Figure 8*).
- Otherwise, if the time for V_{CAP_1} and V_{CAP_2} to reach V_{12} minimum value is slower than the time for V_{DD} to reach 1.7 V, then PA0 could be asserted low externally (see *Figure 9*).
- If V_{CAP_1} and V_{CAP_2} go below V_{12} minimum value and V_{DD} is higher than 1.7 V, then a reset must be asserted on PA0 pin.

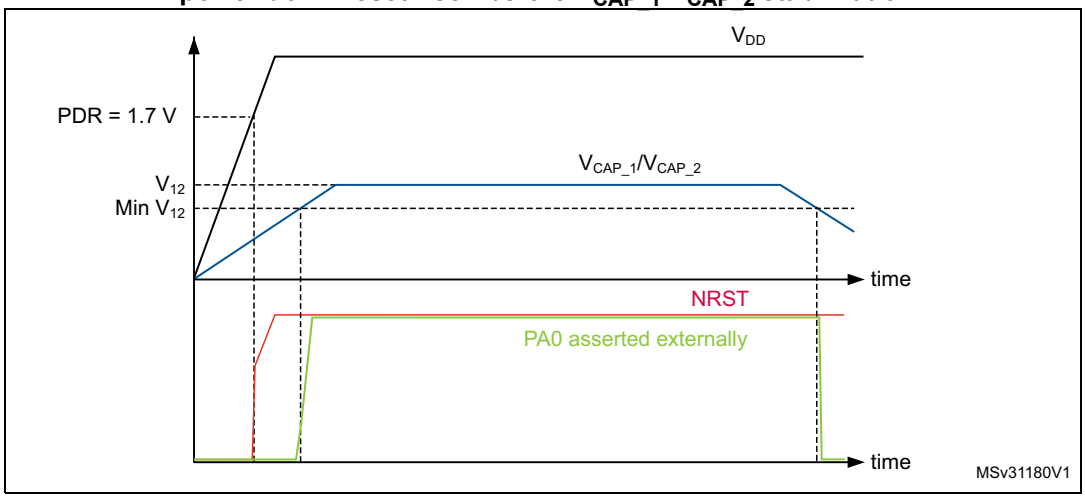
Note: The minimum value of V_{12} depends on the maximum frequency targeted in the application

Figure 8. Startup in regulator OFF: slow V_{DD} slope - power-down reset risen after V_{CAP_1}/V_{CAP_2} stabilization



1. This figure is valid whatever the internal reset mode (ON or OFF).

Figure 9. Startup in regulator OFF mode: fast V_{DD} slope - power-down reset risen before V_{CAP_1}/V_{CAP_2} stabilization



1. This figure is valid whatever the internal reset mode (ON or OFF).

3.15.3 Regulator ON/OFF and internal power supply supervisor availability

Table 3. Regulator ON/OFF and internal power supply supervisor availability

Package	Regulator ON	Regulator OFF	Power supply supervisor ON	Power supply supervisor OFF
UFQFPN48	Yes	No	Yes	No
WLCSP49	Yes	No	Yes PDR_ON set to VDD	Yes PDR_ON external control(1)
LQFP64	Yes	No	Yes	No
LQFP100	Yes	No	Yes	No
UFBGA100	Yes BYPASS_REG set to VSS	Yes BYPASS_REG set to VDD	Yes PDR_ON set to VDD	Yes PDR_ON external control (1)

1. Refer to *Section 3.14: Power supply supervisor*

3.16 Real-time clock (RTC) and backup registers

The backup domain includes:

- The real-time clock (RTC)
- 20 backup registers

The real-time clock (RTC) is an independent BCD timer/counter. Dedicated registers contain the second, minute, hour (in 12/24 hour), week day, date, month, year, in BCD (binary-coded decimal) format. Correction for 28, 29 (leap year), 30, and 31 day of the month are performed automatically. The RTC features a reference clock detection, a more precise second source clock (50 or 60 Hz) can be used to enhance the calendar precision. The RTC provides a programmable alarm and programmable periodic interrupts with wakeup from Stop and Standby modes. The sub-seconds value is also available in binary format.

It is clocked by a 32.768 kHz external crystal, resonator or oscillator, the internal low-power RC oscillator or the high-speed external clock divided by 128. The internal low-speed RC has a typical frequency of 32 kHz. The RTC can be calibrated using an external 512 Hz output to compensate for any natural quartz deviation.

Two alarm registers are used to generate an alarm at a specific time and calendar fields can be independently masked for alarm comparison. To generate a periodic interrupt, a 16-bit programmable binary auto-reload downcounter with programmable resolution is available and allows automatic wakeup and periodic alarms from every 120 µs to every 36 hours.

A 20-bit prescaler is used for the time base clock. It is by default configured to generate a time base of 1 second from a clock at 32.768 kHz.

The backup registers are 32-bit registers used to store 80 bytes of user application data when V_{DD} power is not present. Backup registers are not reset by a system, a power reset, or when the device wakes up from the Standby mode (see *Section 3.17: Low-power modes*).

Additional 32-bit registers contain the programmable alarm subseconds, seconds, minutes, hours, day, and date.

The RTC and backup registers are supplied through a switch that is powered either from the V_{DD} supply when present or from the V_{BAT} pin.

3.17 Low-power modes

The devices support three low-power modes to achieve the best compromise between low power consumption, short startup time and available wakeup sources:

- **Sleep mode**

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

- **Stop mode**

  The Stop mode achieves the lowest power consumption while retaining the contents of SRAM and registers. All clocks in the 1.2 V domain are stopped, the PLL, the HSI RC and the HSE crystal oscillators are disabled. The voltage regulator can also be put either in normal or in low-power mode.

  The device can be woken up from the Stop mode by any of the EXTI line (the EXTI line source can be one of the 16 external lines, the PVD output, the RTC alarm/ wakeup/ tamper/ time stamp events).

- **Standby mode**

  The Standby mode is used to achieve the lowest power consumption. The internal voltage regulator is switched off so that the entire 1.2 V domain is powered off. The PLL, the HSI RC and the HSE crystal oscillators are also switched off. After entering Standby mode, the SRAM and register contents are lost except for registers in the backup domain when selected.

  The device exits the Standby mode when an external reset (NRST pin), an IWDG reset, a rising edge on the WKUP pin, or an RTC alarm/ wakeup/ tamper/time stamp event occurs.

  Standby mode is not supported when the embedded voltage regulator is bypassed and the 1.2 V domain is controlled by an external power.

3.18 V_{BAT} operation

The VBAT pin allows to power the device V_{BAT} domain from an external battery, an external super-capacitor, or from V_{DD} when no external battery and an external super-capacitor are present.

V_{BAT} operation is activated when V_{DD} is not present.

The VBAT pin supplies the RTC and the backup registers.

Note: When the microcontroller is supplied from VBAT, external interrupts and RTC alarm/events do not exit it from V_{BAT} operation. When PDR_ON pin is not connected to V_{DD} (internal Reset OFF), the V_{BAT} functionality is no more available and VBAT pin should be connected to V_{DD}.

3.19 Timers and watchdogs

The devices embed one advanced-control timer, seven general-purpose timers and two watchdog timers.

All timer counters can be frozen in debug mode.

Table 4 compares the features of the advanced-control and general-purpose timers.

Table 4. Timer feature comparison

Timer type	Timer	Counter resolution	Counter type	Prescaler factor	DMA request generation	Capture/ compare channels	Complementary output	Max. interface clock (MHz)	Max. timer clock (MHz)
Advanced-control	TIM1	16-bit	Up, Down, Up/down	Any integer between 1 and 65536	Yes	4	Yes	84	84
General purpose	TIM2, TIM5	32-bit	Up, Down, Up/down	Any integer between 1 and 65536	Yes	4	No	42	84
	TIM3, TIM4	16-bit	Up, Down, Up/down	Any integer between 1 and 65536	Yes	4	No	42	84
	TIM9	16-bit	Up	Any integer between 1 and 65536	No	2	No	84	84
	TIM10, TIM11	16-bit	Up	Any integer between 1 and 65536	No	1	No	84	84

3.19.1 Advanced-control timers (TIM1)

The advanced-control timer (TIM1) can be seen as three-phase PWM generators multiplexed on 4 independent channels. It has complementary PWM outputs with programmable inserted dead times. It can also be considered as a complete general-purpose timer. Its 4 independent channels can be used for:

- Input capture
- Output compare
- PWM generation (edge- or center-aligned modes)
- One-pulse mode output

If configured as standard 16-bit timers, it has the same features as the general-purpose TIMx timers. If configured as a 16-bit PWM generator, it has full modulation capability (0-100%).

The advanced-control timer can work together with the TIMx timers via the Timer Link feature for synchronization or event chaining.

TIM1 supports independent DMA request generation.

3.19.2 General-purpose timers (TIMx)

There are seven synchronizable general-purpose timers embedded in the STM32F401xD/xE (see *Table 4* for differences).

- **TIM2, TIM3, TIM4, TIM5**

  The STM32F401xD/xE devices are 4 full-featured general-purpose timers: TIM2, TIM5, TIM3, and TIM4.The TIM2 and TIM5 timers are based on a 32-bit auto-reload up/downcounter and a 16-bit prescaler. The TIM3 and TIM4 timers are based on a 16-bit auto-reload up/downcounter and a 16-bit prescaler. They all feature four independent channels for input capture/output compare, PWM or one-pulse mode output. This gives up to 15 input capture/output compare/PWMs.

  The TIM2, TIM3, TIM4, TIM5 general-purpose timers can work together, or with the other general-purpose timers and the advanced-control timers TIM1 and TIM8 via the Timer Link feature for synchronization or event chaining.

  Any of these general-purpose timers can be used to generate PWM outputs.

  TIM2, TIM3, TIM4, TIM5 all have independent DMA request generation. They are capable of handling quadrature (incremental) encoder signals and the digital outputs from 1 to 4 hall-effect sensors.

- **TIM9, TIM10 and TIM11**

  These timers are based on a 16-bit auto-reload upcounter and a 16-bit prescaler. TIM10 and TIM11 feature one independent channel, whereas TIM9 has two independent channels for input capture/output compare, PWM or one-pulse mode output. They can be synchronized with the TIM2, TIM3, TIM4, TIM5 full-featured general-purpose timers. They can also be used as simple time bases.

3.19.3 Independent watchdog

The independent watchdog is based on a 12-bit downcounter and 8-bit prescaler. It is clocked from an independent 32 kHz internal RC 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-configurable through the option bytes.

3.19.4 Window watchdog

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.

3.19.5 SysTick timer

This timer is dedicated to real-time operating systems, but could also be used as a standard downcounter. It features:

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

3.20 Inter-integrated circuit interface (I^2C)

Up to three I^2C bus interfaces can operate in multimaster and slave modes. They can support the standard (up to 100 kHz) and fast (up to 400 kHz) modes. The I2C bus frequency can be increased up to 1 MHz. For more details about the complete solution, please contact your local ST sales representative.They also support the 7/10-bit addressing mode and the 7-bit dual addressing mode (as slave). A hardware CRC generation/verification is embedded.

They can be served by DMA and they support SMBus 2.0/PMBus.

The devices also include programmable analog and digital noise filters (see *Table 5*).

Table 5. Comparison of I2C analog and digital filters

	Analog filter	Digital filter
Pulse width of suppressed spikes	≥ 50 ns	Programmable length from 1 to 15 I2C peripheral clocks

3.21 Universal synchronous/asynchronous receiver transmitters (USART)

The devices embed three universal synchronous/asynchronous receiver transmitters (USART1, USART2 and USART6).

These three interfaces provide asynchronous communication, IrDA SIR ENDEC support, multiprocessor communication mode, single-wire half-duplex communication mode and have LIN Master/Slave capability. The USART1 and USART6 interfaces are able to communicate at speeds of up to 10.5 Mbit/s. The USART2 interface communicates at up to 5.25 bit/s.

USART1 and USART2 also provide hardware management of the CTS and RTS signals, Smart Card mode (ISO 7816 compliant) and SPI-like communication capability. All interfaces can be served by the DMA controller.

Table 6. USART feature comparison

USART name	Standard features	Modem (RTS/CTS)	LIN	SPI master	irDA	Smartcard (ISO 7816)	Max. baud rate in Mbit/s (oversampling by 16)	Max. baud rate in Mbit/s (oversampling by 8)	APB mapping
USART1	X	X	X	X	X	X	5.25	10.5	APB2 (max. 84 MHz)
USART2	X	X	X	X	X	X	2.62	5.25	APB1 (max. 42 MHz)
USART6	X	N.A	X	X	X	X	5.25	10.5	APB2 (max. 84 MHz)

3.22 Serial peripheral interface (SPI)

The devices feature up to four SPIs in slave and master modes in full-duplex and simplex communication modes. SPI1 and SPI4 can communicate at up to 42 Mbit/s, SPI2 and SPI3 can communicate at up to 21 Mbit/s. The 3-bit prescaler gives 8 master mode frequencies and the frame is configurable to 8 bits or 16 bits. The hardware CRC generation/verification supports basic SD Card/MMC modes. All SPIs can be served by the DMA controller.

The SPI interface can be configured to operate in TI mode for communications in master mode and slave mode.

3.23 Inter-integrated sound (I^2S)

Two standard I^2S interfaces (multiplexed with SPI2 and SPI3) are available. They can be operated in master or slave mode, in full duplex and simplex communication modes and can be configured to operate with a 16-/32-bit resolution as an input or output channel. Audio sampling frequencies from 8 kHz up to 192 kHz are supported. When either or both of the I^2S interfaces is/are configured in master mode, the master clock can be output to the external DAC/CODEC at 256 times the sampling frequency.

All I^2Sx can be served by the DMA controller.

3.24 Audio PLL (PLLI2S)

The devices feature an additional dedicated PLL for audio I^2S application. It allows to achieve error-free I^2S sampling clock accuracy without compromising on the CPU performance.

The PLLI2S configuration can be modified to manage an I^2S sample rate change without disabling the main PLL (PLL) used for the CPU.

The audio PLL can be programmed with very low error to obtain sampling rates ranging from 8 kHz to 192 kHz.

In addition to the audio PLL, a master clock input pin can be used to synchronize the I2S flow with an external PLL (or Codec output).

3.25 Secure digital input/output interface (SDIO)

An SD/SDIO/MMC host interface is available, that supports MultiMediaCard System Specification Version 4.2 in three different databus modes: 1-bit (default), 4-bit and 8-bit.

The interface allows data transfer at up to 48 MHz, and is compliant with the SD Memory Card Specification Version 2.0.

The SDIO Card Specification Version 2.0 is also supported with two different databus modes: 1-bit (default) and 4-bit.

The current version supports only one SD/SDIO/MMC4.2 card at any one time and a stack of MMC4.1 or previous.

In addition to SD/SDIO/MMC, this interface is fully compliant with the CE-ATA digital protocol Rev1.1.

3.26 Universal serial bus on-the-go full-speed (OTG_FS)

The devices embed an USB OTG full-speed device/host/OTG peripheral with integrated transceivers. The USB OTG FS peripheral is compliant with the USB 2.0 specification and with the OTG 1.0 specification. It has software-configurable endpoint setting and supports suspend/resume. The USB OTG full-speed controller requires a dedicated 48 MHz clock that is generated by a PLL connected to the HSE oscillator. The major features are:

- Combined Rx and Tx FIFO size of 320 × 35 bits with dynamic FIFO sizing
- Supports the session request protocol (SRP) and host negotiation protocol (HNP)
- 4 bidirectional endpoints
- 8 host channels with periodic OUT support
- HNP/SNP/IP inside (no need for any external resistor)
- For OTG/Host modes, a power switch is needed in case bus-powered devices are connected

3.27 General-purpose input/outputs (GPIOs)

Each of the GPIO pins can be configured by software as output (push-pull or open-drain, with or without pull-up or pull-down), as input (floating, 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. All GPIOs are high-current-capable and have speed selection to better manage internal noise, power consumption and electromagnetic emission.

The I/O configuration can be locked if needed by following a specific sequence in order to avoid spurious writing to the I/Os registers.

Fast I/O handling allowing maximum I/O toggling up to 84 MHz.

3.28 Analog-to-digital converter (ADC)

One 12-bit analog-to-digital converter is embedded and shares up to 16 external channels, performing conversions in the single-shot or scan mode. In scan mode, automatic conversion is performed on a selected group of analog inputs.

The ADC can be served by the DMA controller. An analog watchdog feature allows very precise monitoring of the converted voltage of one, some or all selected channels. An interrupt is generated when the converted voltage is outside the programmed thresholds.

To synchronize A/D conversion and timers, the ADCs could be triggered by any of TIM1, TIM2, TIM3, TIM4 or TIM5 timer.

3.29 Temperature sensor

The temperature sensor has to generate a voltage that varies linearly with temperature. The conversion range is between 1.7 V and 3.6 V. The temperature sensor is internally connected to the ADC_IN16 input channel which is used to convert the sensor output voltage into a digital value. Refer to the reference manual for additional information.

As the offset of the temperature sensor varies from chip to chip due to process variation, the internal temperature sensor is mainly suitable for applications that detect temperature changes instead of absolute temperatures. If an accurate temperature reading is needed, then an external temperature sensor part should be used.

3.30 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 2 pins only instead of 5 required by the JTAG (JTAG pins could be re-use 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.

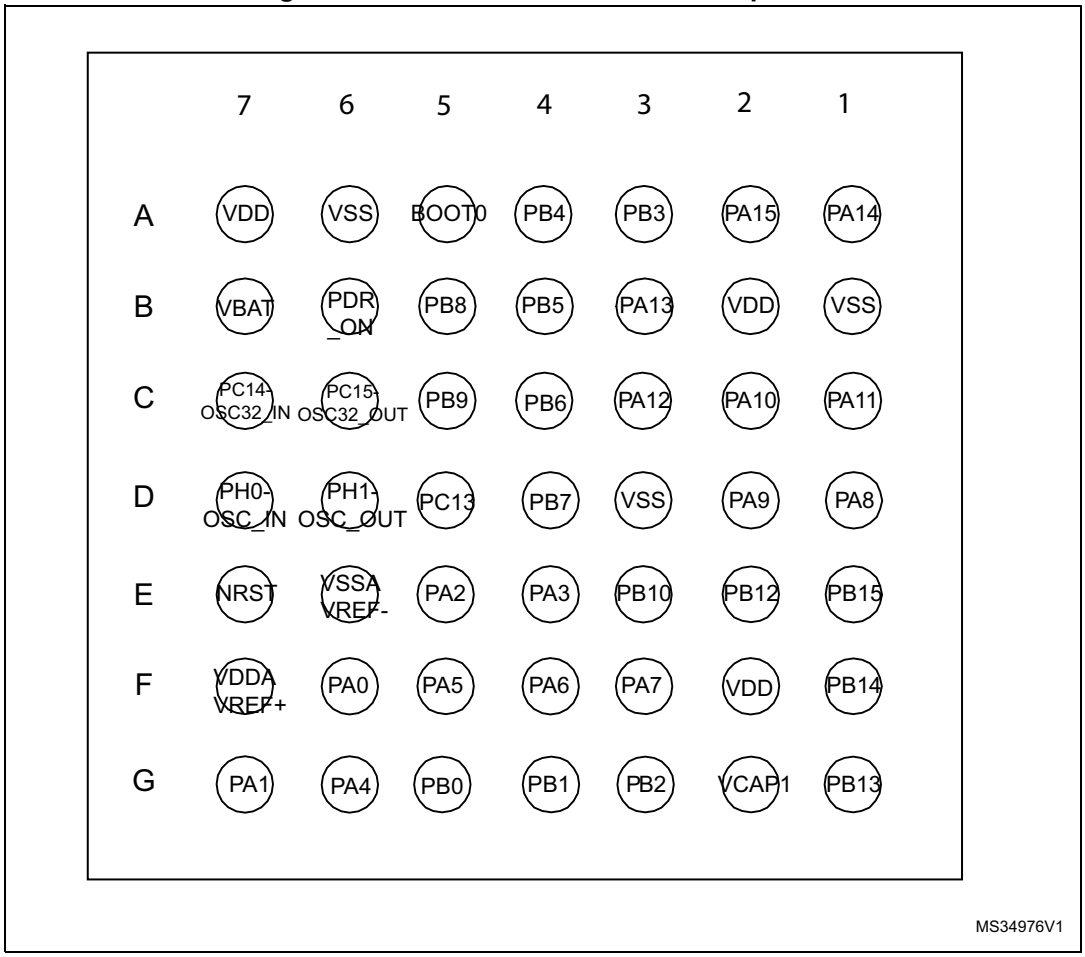
3.31 Embedded Trace Macrocell™

The ARM Embedded Trace Macrocell 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 STM32F401xD/xE through a small number of ETM pins to an external hardware trace port analyzer (TPA) device. The TPA is connected to a host computer using any high-speed channel available. Real-time instruction and data flow activity can be recorded and then formatted for display on the host computer that runs the debugger software. TPA hardware is commercially available from common development tool vendors.

The Embedded Trace Macrocell operates with third party debugger software tools.

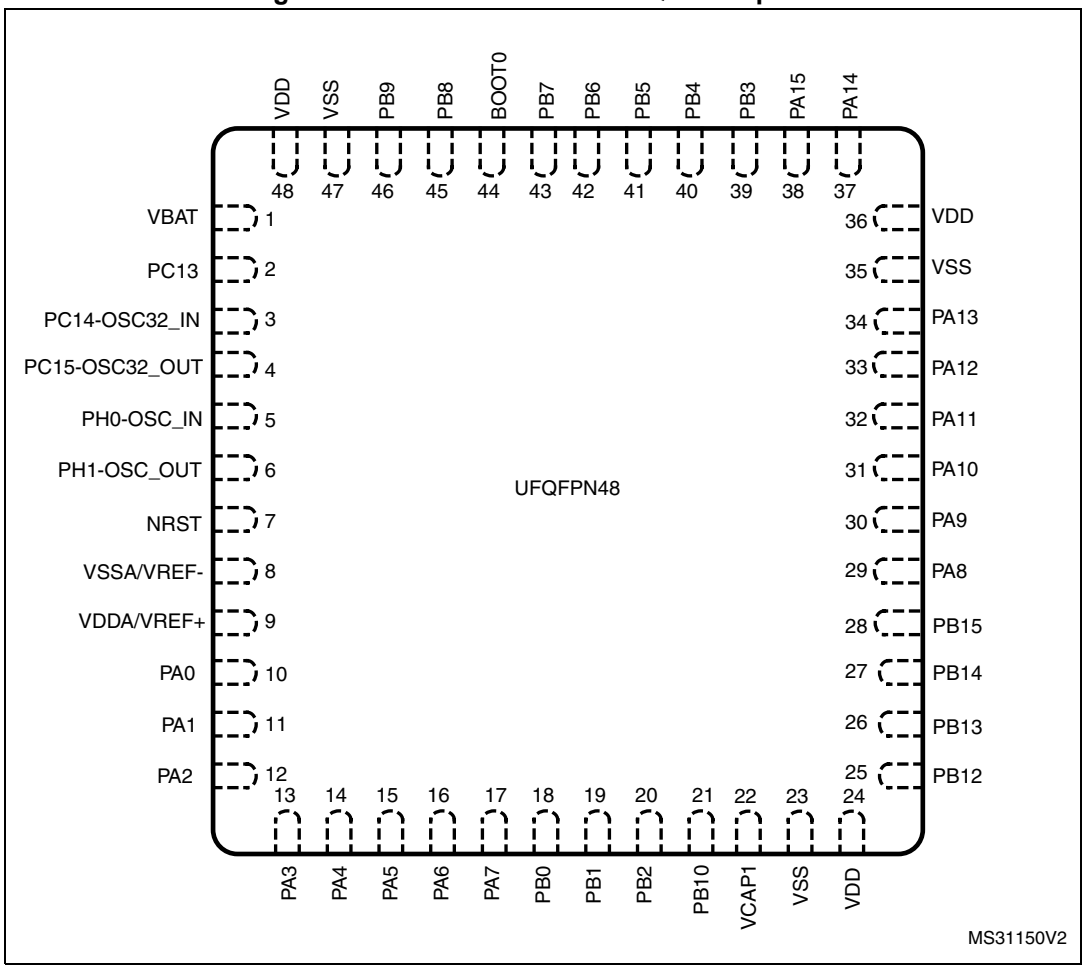
4 Pinouts and pin description

Figure 10. STM32F401xD/xE WLCSP49 pinout



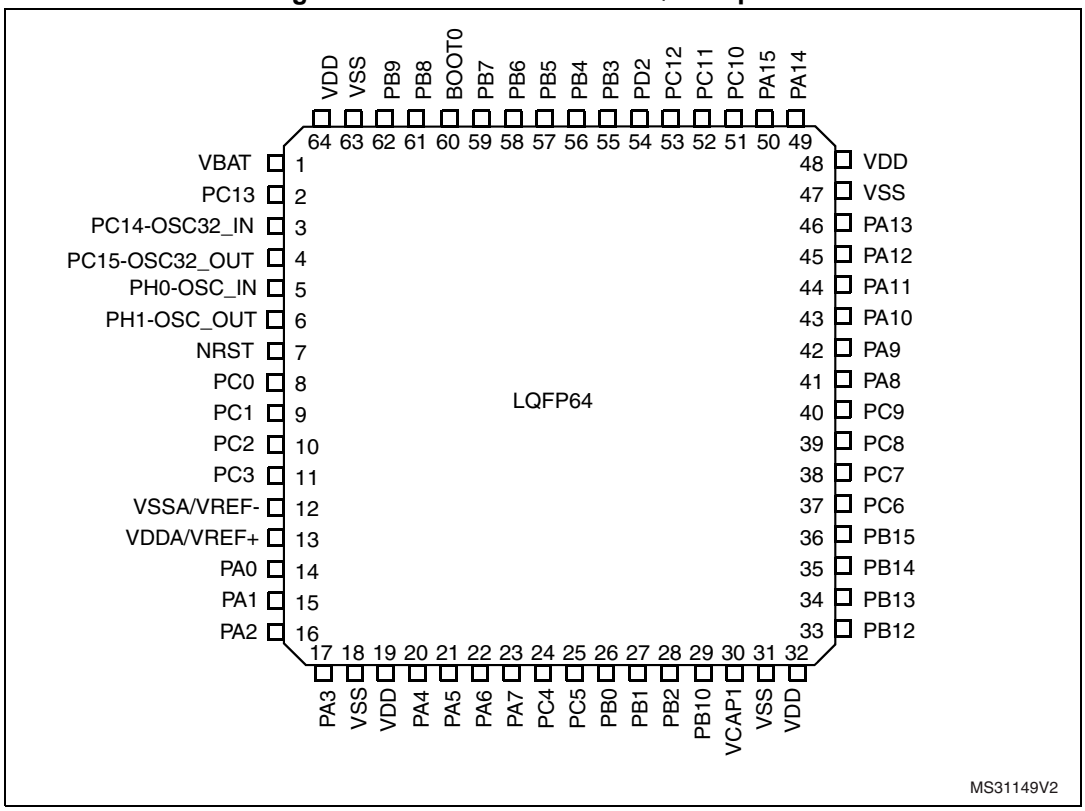
1. The above figure shows the package bump side.

Figure 11. STM32F401xD/xE UFQFPN48 pinout



1. The above figure shows the package top view.

Figure 12. STM32F401xD/xE LQFP64 pinout



1. The above figure shows the package top view.