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Applications of "Embedded - Microcontrollers"

Details	
Product Status	Active
Core Processor	ARM® Cortex®-M4
Core Size	32-Bit Single-Core
Speed	180MHz
Connectivity	CANbus, EBI/EMI, I²C, IrDA, LINbus, SAI, SD, SPDIF-Rx, SPI, UART/USART, USB, USB OTG
Peripherals	Brown-out Detect/Reset, DMA, I²S, LVD, POR, PWM, WDT
Number of I/O	114
Program Memory Size	512KB (512K x 8)
Program Memory Type	FLASH
EEPROM Size	-
RAM Size	128K x 8
Voltage - Supply (Vcc/Vdd)	1.7V ~ 3.6V
Data Converters	A/D 24x12b; D/A 2x12b
Oscillator Type	Internal
Operating Temperature	-40°C ~ 85°C (TA)
Mounting Type	Surface Mount
Package / Case	144-UFBGA
Supplier Device Package	144-UFBGA (7x7)
Purchase URL	https://www.e-xfl.com/product-detail/stmicroelectronics/stm32f446zeh6

Figure 3. STM32F446xC/E block diagram

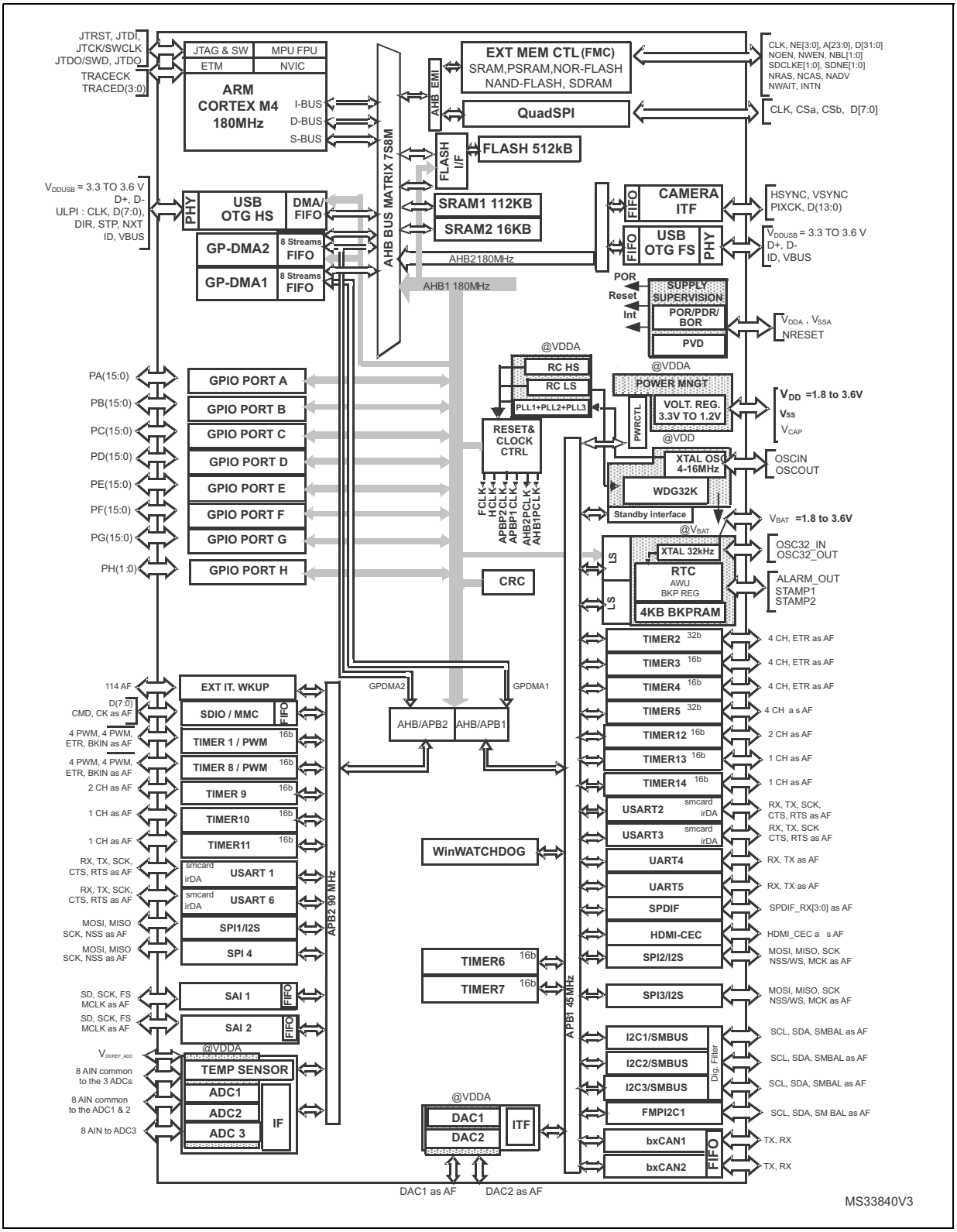


Table 4. Regulator ON/OFF and internal reset ON/OFF availability

Package	Regulator ON	Regulator OFF	Internal reset ON	Internal reset OFF
LQFP144	Yes	No	Yes PDR_ON set to V_{DD}	Yes PDR_ON set to VSS
UFBGA144	Yes BYPASS_REG set to Vss	Yes BYPASS_REG set to VDD		
WLCSP81				

3.18 Real-time clock (RTC), backup SRAM and backup registers

The backup domain includes:

- The real-time clock (RTC)
- 4 Kbytes of backup SRAM
- 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 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 4-Kbyte backup SRAM is an EEPROM-like memory area. It can be used to store data which need to be retained in VBAT and standby mode. This memory area is disabled by default to minimize power consumption (see *Section 3.19: Low-power modes*). It can be enabled by software.

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 3.19: Low-power modes*).

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

Like backup SRAM, 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.

3.23 Universal synchronous/asynchronous receiver transmitters (USART)

The devices embed four universal synchronous/asynchronous receiver transmitters (USART1, USART2, USART3 and USART6) and four universal asynchronous receiver transmitters (UART4, and UART5).

These six 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 11.25 Mbit/s. The other available interfaces communicate at up to 5.62 bit/s.

USART1, USART2, USART3 and USART6 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 8. USART feature comparison(1)

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	5.62	11.25	APB2 (max. 90 MHz)
USART2	X	X	X	X	X	X	2.81	5.62	APB1 (max. 45 MHz)
USART3	X	X	X	X	X	X	2.81	5.62	APB1 (max. 45 MHz)
UART4	X	X	X	-	X	-	2.81	5.62	APB1 (max. 45 MHz)
UART5	X	X	X	-	X	-	2.81	5.62	APB1 (max. 45 MHz)
USART6	X	X	X	X	X	X	5.62	11.25	APB2 (max. 90 MHz)

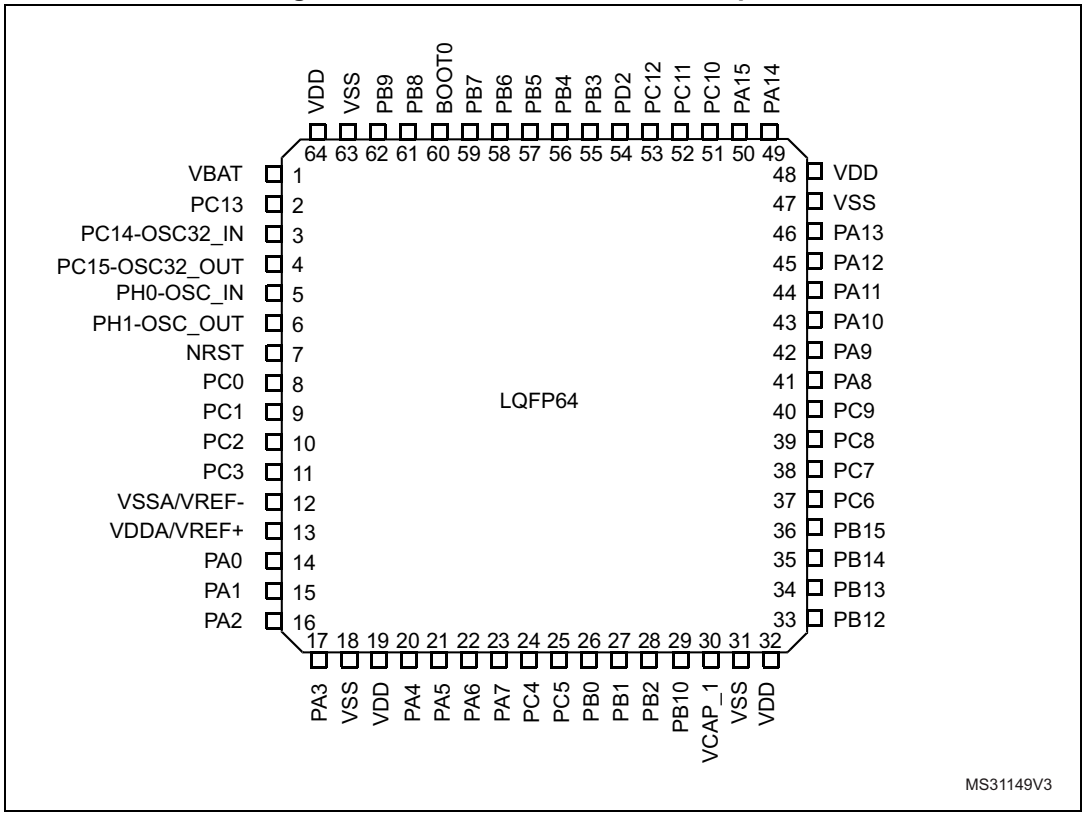
1. X = feature supported.

3.24 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 45 Mbits/s, SPI2 and SPI3 can communicate at up to 22.5 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.

4 Pinout and pin description

Figure 10. STM32F446xC/xE LQFP64 pinout



1. The above figure shows the package top view.

Table 10. STM32F446xx pin and ball descriptions (continued)

Pin Number					Pin name (function after reset)	Pin type	I/O structure	Notes	Alternate functions	Additional functions
LQFP64	LQFP100	WLCSP 81	UFBGA144	LQFP144						
17	26	E6	M2	37	PA3	I/O	FT	-	TIM2_CH4, TIM5_CH4, TIM9_CH2, SAI1_FS_A, USART2_RX, OTG_HS_ULPI_D0, EVENTOUT	ADC123_IN3
18	27	-	G4	38	VSS	S	-	-	-	-
-	-	J8	H5	-	BYPASS_REG	I	FT	-	-	-
19	28	-	F4	39	VDD	S	-	-	-	-
20	29	H7	J3	40	PA4	I/O	TC	-	SPI1_NSS/I2S1_WS, SPI3_NSS/I2S3_WS, USART2_CK, OTG_HS_SOF, DCMI_HSYNC, EVENTOUT	ADC12_IN4, DAC_OUT1
21	30	F6	K3	41	PA5	I/O	TC	-	TIM2_CH1/TIM2_ETR, TIM8_CH1N, SPI1_SCK/I2S1_CK, OTG_HS_ULPI_CK, EVENTOUT	ADC12_IN5, DAC_OUT2
22	31	G6	L3	42	PA6	I/O	FT	-	TIM1_BKIN, TIM3_CH1, TIM8_BKIN, SPI1_MISO, I2S2_MCK, TIM13_CH1, DCMI_PIXCLK, EVENTOUT	ADC12_IN6
23	32	E5	M3	43	PA7	I/O	FT	-	TIM1_CH1N, TIM3_CH2, TIM8_CH1N, SPI1_MOSI/I2S1_SD, TIM14_CH1, FMC_SDNWE, EVENTOUT	ADC12_IN7
24	33	J7	J4	44	PC4	I/O	FT	-	I2S1_MCK, SPDIFRX_IN2, FMC_SDNE0, EVENTOUT	ADC12_IN14
25	34	-	K4	45	PC5	I/O	FT	-	USART3_RX, SPDIFRX_IN3, FMC_SDCKE0, EVENTOUT	ADC12_IN15

Table 10. STM32F446xx pin and ball descriptions (continued)

Pin Number					Pin name (function after reset)	Pin type	I/O structure	Notes	Alternate functions	Additional functions
LQFP64	LQFP100	WLCSP 81	UFBGA144	LQFP144						
56	90	B5	A6	134	PB4(NJTRST)	I/O	FT	-	NJTRST, TIM3_CH1, I2C3_SDA, SPI1_MISO, SPI3_MISO, SPI2_NSS/I2S2_WS, EVENTOUT	-
57	91	A6	B6	135	PB5	I/O	FT	-	TIM3_CH2, I2C1_SMBA, SPI1_MOSI/I2S1_SD, SPI3_MOSI/I2S3_SD, CAN2_RX, OTG_HS_ULPI_D7, FMC_SDCKE1, DCMI_D10, EVENTOUT	-
58	92	C5	C6	136	PB6	I/O	FT	-	TIM4_CH1, HDMI_CEC, I2C1_SCL, USART1_TX, CAN2_TX, QUADSPI_BK1_NCS, FMC_SDNE1, DCMI_D5, EVENTOUT	-
59	93	B6	D6	137	PB7	I/O	FT	-	TIM4_CH2, I2C1_SDA, USART1_RX, SPDIFRX_IN0, FMC_NL, DCMI_VSYNC, EVENTOUT	-
60	94	A7	D5	138	BOOT0	I	B	-	-	VPP
61	95	C6	C5	139	PB8	I/O	FT	-	TIM2_CH1/TIM2_ETR, TIM4_CH3, TIM10_CH1, I2C1_SCL, CAN1_RX, SDIO_D4, DCMI_D6, EVENTOUT	-
62	96	C7	B5	140	PB9	I/O	FT	-	TIM2_CH2, TIM4_CH4, TIM11_CH1, I2C1_SDA, SPI2_NSS/I2S2_WS, SAI1_FS_B, CAN1_TX, SDIO_D5, DCMI_D7, EVENTOUT	-
-	97	-	A5	141	PE0	I/O	FT	-	TIM4_ETR, SAI2_MCLK_A, FMC_NBL0, DCMI_D2, EVENTOUT	-
-	98	-	A4	142	PE1	I/O	FT	-	FMC_NBL1, DCMI_D3, EVENTOUT	-

Table 11. Alternate function (continued)

Port		AF0	AF1	AF2	AF3	AF4	AF5	AF6	AF7	AF8	AF9	AF10	AF11	AF12	AF13	AF14	AF15
		SYS	TIM1/2	TIM3/4/5	TIM8/9/10/11/CEC	I2C1/2/3/4/CEC	SPI1/2/3/4	SPI2/3/4/SAI1	SPI2/3/USART1/2/3/UART5/SPDIFRX	SAI/USART6/UART4/5/SPDIFRX	CAN1/2 TIM12/13/14/QUADSPI	SAI2/QUADSPI/OTG2_HS/OTG1_FS	OTG1_FS	FMC/SDIO/OTG2_FS	DCMI	-	SYS
Port G	PG0	-	-	-	-	-	-	-	-	-	-	-	-	FMC_A10	-	-	EVENTOUT
	PG1	-	-	-	-	-	-	-	-	-	-	-	-	FMC_A11	-	-	EVENTOUT
	PG2	-	-	-	-	-	-	-	-	-	-	-	-	FMC_A12	-	-	EVENTOUT
	PG3	-	-	-	-	-	-	-	-	-	-	-	-	FMC_A13	-	-	EVENTOUT
	PG4	-	-	-	-	-	-	-	-	-	-	-	-	FMC_A14/FMC_BA0	-	-	EVENTOUT
	PG5	-	-	-	-	-	-	-	-	-	-	-	-	FMC_A15/FMC_BA1	-	-	EVENTOUT
	PG6	-	-	-	-	-	-	-	-	-	-	QUADSPI_BK1_NCS	-	-	DCMI_D12	-	EVENTOUT
	PG7	-	-	-	-	-	-	-	-	USART6_CK	-	-	-	FMC_INT	DCMI_D13	-	EVENTOUT
	PG8	-	-	-	-	-	-	-	SPDIFRX_IN2	USART6_RTS	-	-	-	FMC_SDCLK	-	-	EVENTOUT
	PG9	-	-	-	-	-	-	-	SPDIFRX_IN3	USART6_RX	QUADSPI_BK2_IO2	SAI2_FS_B	-	FMC_NE2/FMC_NCE3	DCMI_VSYNC(1)	-	EVENTOUT
	PG10	-	-	-	-	-	-	-	-	-	-	SAI2_SD_B	-	FMC_NE3	DCMI_D2	-	EVENTOUT
	PG11	-	-	-	-	-	-	SPI4_SCK	SPDIFRX_IN0	-	-	-	-	-	DCMI_D3	-	EVENTOUT
	PG12	-	-	-	-	-	-	SPI4_MISO	SPDIFRX_IN1	USART6_RTS	-	-	-	FMC_NE4	-	-	EVENTOUT
	PG13	TRACED2	-	-	-	-	-	SPI4_MOSI	-	USART6_CTS	-	-	-	FMC_A24	-	-	EVENTOUT
	PG14	TRACED3	-	-	-	-	-	SPI4_NSS	-	USART6_TX	QUADSPI_BK2_IO3	-	-	FMC_A25	-	-	EVENTOUT
	PG15	-	-	-	-	-	-	-	-	USART6_CTS	-	-	-	FMC_SDNCAS	DCMI_D13	-	EVENTOUT

Table 23. Typical and maximum current consumption in Run mode, code with data processing running from Flash memory (ART accelerator enabled except prefetch) or RAM(1)

Symbol	Parameter	Conditions	f_{HCLK} (MHz)	Typ	Max(2)			Unit
					T_A = 25 °C	T_A = 85 °C	T_A = 105 °C	
I_{DD}	Supply current in RUN mode	External clock, PLL ON, all peripherals enabled(3)(4)	180	72	83.0(5)	100.0	110.0(5)	mA
			168	65	71.0	95.3	101.0	
			150	59	63.6	85.4	100.8	
			144(6)	54	58.4	78.8	91.2	
			120	40	44.9	62.1	73.2	
			90	30	35.3	50.7	60.0	
			60	21	25.5	39.2	46.8	
			30	12	16.2	28.1	36.0	
			25	10	14.41	26.17	32.4	
		HSI, PLL OFF, all peripherals enabled	16	6	11.4	23.1	25.2	
			8	3	9.5	20.3	22.5	
			4	2.3	8.3	18.9	21.1	
			2	1.8	7.7	18.1	20.5	
		External clock, PLL ON, all Peripherals disabled(3)	180	32	42.0(5)	59.0	75.0(5)	
			168	29	35.5	51.4	55.7	
			150	26	31.5	47.8	51.9	
			144(6)	24	29.2	44.7	48.6	
			120	18	23.3	36.8	40.4	
			90	14	19.0	31.8	35.1	
			60	10	14.7	26.9	29.9	
			30	6	10.7	22.1	24.9	
			25	5	9.96	21.24	24.02	
		HSI, PLL OFF, all peripherals disabled(3)	16	3	8.7	18.9	21.9	
			8	2	8.1	17.8	20.9	
			4	1.7	7.64	17.23	20.32	
			2	1.4	7.4	16.94	20.03	

1. Code and data processing running from SRAM1 using boot pins.
2. Guaranteed based on test during characterization.
3. When analog peripheral blocks such as ADCs, DACs, HSE, LSE, HSI, or LSI are ON, an additional power consumption should be considered.
4. When the ADC is ON (ADON bit set in the ADC_CR2 register), add an additional power consumption of 1.6 mA per ADC for the analog part.
5. Tested in production.
6. Overdrive OFF

Table 26. Typical and maximum current consumption in Sleep mode(1) (continued)

Symbol	Parameter	Conditions		fHCLK (MHz)	Typ	Max			Unit
						T_A = 25 °C	T_A = 25 °C	T_A = 25 °C	
IDD	Supply current in Sleep mode	External clock, PLL on all peripherals disabled	Flash on	180	11.36	17.59	28.2	51.6	mA
				168(2)	10.20	16.19	22.0	31.8	
				150	9.53	15.59	21.1	30.9	
				144(2)	8.90	14.87	19.7	28.4	
				120	7.35	13.24	16.5	23.3	
				90	6.39	12.40	15.3	21.9	
				60	5.28	11.17	14.1	20.7	
				30	4.43	10.31	13.1	19.6	
				25	4.23	10.12	12.85	19.30	
			Flash in Deep Power Down mode	180	8.3	13.44	30.72	37.20	
				168(2)	7.3	12.25	25.16	28.80	
				150	6.7	11.60	24.27	27.84	
				144(2)	6.1	11.08	23.25	26.28	
				120	4.7	9.64	20.95	23.72	
				90	3.8	8.80	19.77	22.57	
				60	2.8	7.74	18.69	21.32	
				30	2.0	6.89	17.66	20.40	
				25	1.8	6.70	17.43	20.17	
			Flash in STOP mode	180	8.3	13.44	30.72	37.20	
				168(2)	7.3	12.25	25.16	28.80	
				150	6.7	11.60	24.27	27.84	
				144(2)	6.1	11.08	23.25	26.28	
				120	4.7	9.64	20.95	23.72	
				90	3.8	8.80	19.77	22.57	
				60	2.8	7.74	18.69	21.32	
				30	2.0	6.89	17.66	20.40	
				25	1.8	6.70	17.43	20.17	

Table 37. High-speed external user clock characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{HSE_ext}	External user clock source frequency(1)	-	1	-	50	MHz
V_{HSEH}	OSC_IN input pin high level voltage		$0.7V_{DD}$	-	V_{DD}	V
V_{HSEL}	OSC_IN input pin low level voltage		V_{SS}	-	$0.3V_{DD}$	
$t_{w(HSE)}$ $t_{w(HSE)}$	OSC_IN high or low time(1)		5	-	-	ns
$t_{r(HSE)}$ $t_{f(HSE)}$	OSC_IN rise or fall time(1)		-	-	10	
$C_{in(HSE)}$	OSC_IN input capacitance(1)	-	-	5	-	pF
$DuCy_{(HSE)}$	Duty cycle	-	45	-	55	%
I_L	OSC_IN Input leakage current	$V_{SS} \le V_{IN} \le V_{DD}$	-	-	±1	µA

1. Guaranteed by design.

Low-speed external user clock generated from an external source

In bypass mode the LSE oscillator is switched off and the input pin is a standard I/O. The external clock signal has to respect the *Table 56: I/O static characteristics*. However, the recommended clock input waveform is shown in *Figure 24*.

The characteristics given in *Table 38* result from tests performed using an low-speed external clock source, and under ambient temperature and supply voltage conditions summarized in *Table 16*.

Table 38. Low-speed external user clock characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{LSE_ext}	User External clock source frequency(1)	-	-	32.768	1000	kHz
V_{LSEH}	OSC32_IN input pin high level voltage		$0.7V_{DD}$	-	V_{DD}	V
V_{LSEL}	OSC32_IN input pin low level voltage		V_{SS}	-	$0.3V_{DD}$	
$t_{w(LSE)}$ $t_{f(LSE)}$	OSC32_IN high or low time(1)		450	-	-	ns
$t_{r(LSE)}$ $t_{f(LSE)}$	OSC32_IN rise or fall time(1)		-	-	200	
$C_{in(LSE)}$	OSC32_IN input capacitance(1)	-	-	5	-	pF
$DuCy_{(LSE)}$	Duty cycle	-	30	-	70	%
I_L	OSC32_IN Input leakage current	$V_{SS} \le V_{IN} \le V_{DD}$	-	-	±1	µA

1. Guaranteed by design.

possible to the oscillator pins in order to minimize output distortion and startup stabilization time. Refer to the crystal resonator manufacturer for more details on the resonator characteristics (frequency, package, accuracy).

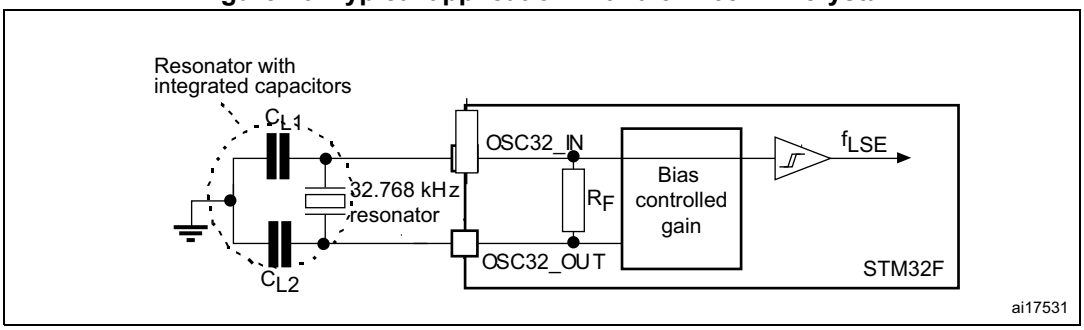
Table 40. LSE oscillator characteristics (f_{LSE} = 32.768 kHz) (1)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
R_F	Feedback resistor	-	-	18.4	-	MΩ
I_{DD}	LSE current consumption	-	-	-	1	µA
ACC_{LSE} (2)	LSE accuracy	-	-500	-	500	ppm
G_m_crit_max	Maximum critical crystal g_m	Startup low-power mode	-	-	0.56	µA/V
		Startup high-drive mode	-	-	1.5	
$t_{SU(LSE)}$ (3)	startup time	V_{DD} is stabilized	-	2	-	s

1. Guaranteed by design.
2. This parameter depends on the crystal used in the application. Refer to application note AN2867.
3. $t_{SU(LSE)}$ is the startup time measured from the moment it is enabled (by software) to a stabilized 32.768 kHz oscillation is reached. This value is guaranteed based on test during characterization. It is measured for a standard crystal resonator and it can vary significantly with the crystal manufacturer.

Note: For information on selecting the crystal, refer to the application note AN2867 "Oscillator design guide for ST microcontrollers" available from the ST website www.st.com.

Figure 26. Typical application with a 32.768 kHz crystal



6.3.17 I/O port characteristics

General input/output characteristics

Unless otherwise specified, the parameters given in *Table 56: I/O static characteristics* are derived from tests performed under the conditions summarized in *Table 16*. All I/Os are CMOS and TTL compliant.

Table 56. I/O static characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{IL}	FT, FTf, TTa and NRST I/O input low level voltage	1.7 V≤V_{DD}≤3.6 V	-	-	$0.35V_{DD}-0.04$(1) $0.3V_{DD}$(2)	V
	BOOT0 I/O input low level voltage	1.75 V ≤ V_{DD} ≤ 3.6 V, – 40 °C≤ T_A ≤ 105 °C	-	-	$0.1V_{DD}+0.1$(1)	
		1.7 V ≤ V_{DD} ≤ 3.6 V, 0 °C ≤ T_A ≤105 °C	-	-		
V_{IH}	FT, FTf, TTa and NRST I/O input high level voltage(4)	1.7 V≤V_{DD}≤3.6 V	$0.45V_{DD}+0.3$(1) $0.7V_{DD}$(2)	-	-	V
	BOOT0 I/O input high level voltage	1.75 V≤V_{DD} ≤3.6 V, – 40 °C≤T_A ≤105 °C	$0.17V_{DD}+0.7$(1)	-	-	
		1.7 V≤V_{DD} ≤3.6 V, 0 °C≤T_A ≤105 °C				
V_{HYS}	FT, FTf, TTa and NRST I/O input hysteresis	1.7 V≤V_{DD}≤3.6 V	-	$10\%V_{DD}$	-	V
	BOOT0 I/O input hysteresis	1.75 V≤V_{DD} ≤3.6 V, –40 °C≤T_A ≤105 °C	-	100m	-	
		1.7 V≤V_{DD} ≤3.6 V, 0 °C≤T_A ≤105 °C	-		-	
I_{lkg}	I/O input leakage current (3)	V_{SS} ≤V_{IN} ≤V_{DD}	-	-	±1	µA
	I/O FT input leakage current (4)	V_{IN} = 5 V	-	-	3	

Figure 35. FMPI^{2}C timing diagram and measurement circuit

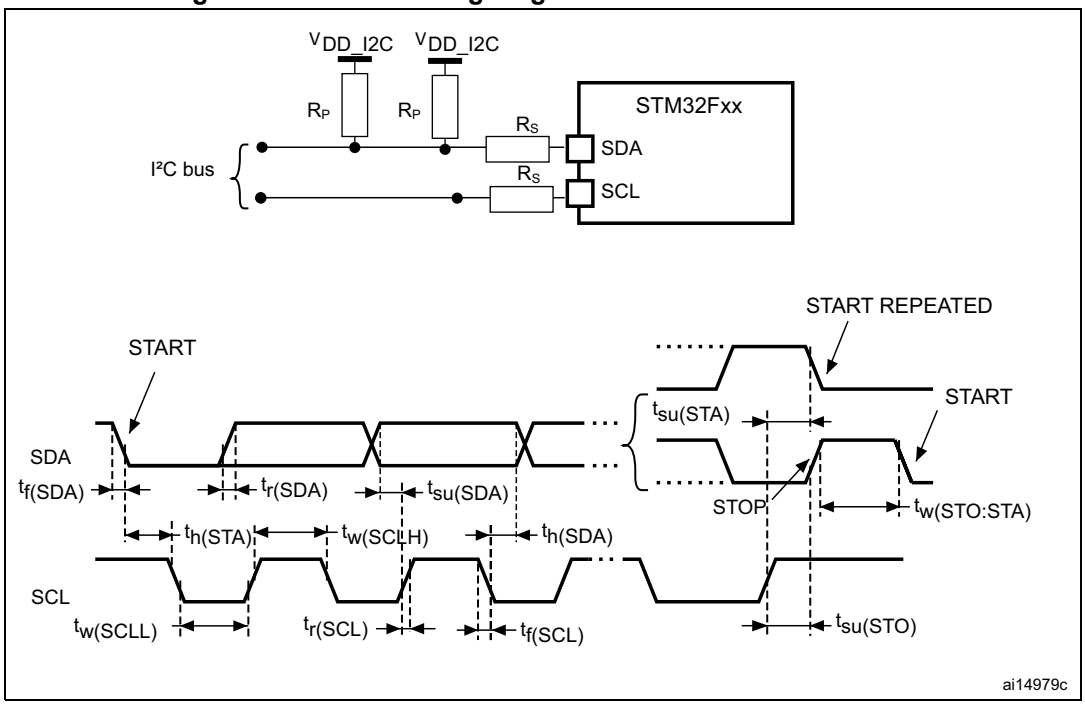


Table 65. QSPI dynamic characteristics in DDR Mode(1) (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$t_{w(CKH)}$	QSPI clock high and low	-	$(T_{(CK)} / 2) - 2$	-	$T_{(CK)} / 2$	ns
$t_{w(CKL)}$			$T_{(CK)} / 2$	-	$(T_{(CK)} / 2) + 2$	
$t_{s(IN)}$	Data input setup time	-	0	-	-	
$t_{h(IN)}$	Data input hold time	-	5.5	-	-	
$t_{v(OUT)}$	Data output valid time	2.7V <VDD< 3.6V	-	5.5	6.5	
		1.71V <VDD< 3.6V	-	8	9.5	
$t_{h(OUT)}$	Data output hold time	-	3.5	-	-	

1. Guaranteed based on test during characterization.

I²S interface characteristics

Unless otherwise specified, the parameters given in *Table 66* for the I²S interface are derived from tests performed under the ambient temperature, f_{PCLKx} frequency and V_{DD} supply voltage conditions summarized in *Table 16*, with the following configuration:

- Output speed is set to OSPEEDRy[1:0] = 10
- Capacitive load C = 30 pF
- Measurement points are done at CMOS levels: $0.5V_{DD}$

Refer to *Section 6.3.17: I/O port characteristics* for more details on the input/output alternate function characteristics (CK, SD, WS).

Table 66. I²S dynamic characteristics(1)

Symbol	Parameter	Conditions	Min	Max	Unit
f_{MCK}	I2S Main clock output	-	256 x 8K	256 x Fs(2)	MHz
f_{CK}	I2S clock frequency	Master data	-	64 x Fs	MHz
		Slave data	-	64 x Fs	
D_{CK}	I2S clock frequency duty cycle	Slave receiver	30	70	%

Table 70. USB OTG full speed electrical characteristics(1)

Driver characteristics					
Symbol	**Parameter**	**Conditions**	**Min**	**Max**	**Unit**
t_r	Rise time(2)	C_L = 50 pF	4	20	ns
t_f	Fall time(2)	C_L = 50 pF	4	20	ns
t_{rfm}	Rise/ fall time matching	t_r/t_f	90	110	%
V_{CRS}	Output signal crossover voltage	-	1.3	2.0	V
Z_{DRV}	Output driver impedance(3)	Driving high or low	28	44	Ω

1. Guaranteed by design.
2. Measured from 10% to 90% of the data signal. For more detailed informations, please refer to USB Specification - Chapter 7 (version 2.0).
3. No external termination series resistors are required on DP (D+) and DM (D-) pins since the matching impedance is included in the embedded driver.

USB high speed (HS) characteristics

Unless otherwise specified, the parameters given in *Table 73* for ULPI are derived from tests performed under the ambient temperature, f_{HCLK} frequency summarized in *Table 72* and V_{DD} supply voltage conditions summarized in *Table 71*, with the following configuration:

- Output speed is set to OSPEEDRy[1:0] = 10, unless otherwise specified
- Capacitive load C = 30 pF, unless otherwise specified
- Measurement points are done at CMOS levels: $0.5V_{DD}$.

Refer to *Section 6.3.17: I/O port characteristics* for more details on the input/output characteristics.

Table 71. USB HS DC electrical characteristics

Symbol		Parameter	Min.(1)	Max.(1)	Unit
Input level	V_{DD}	USB OTG HS operating voltage	1.7	3.6	V

1. All the voltages are measured from the local ground potential.

Table 72. USB HS clock timing parameters(1)

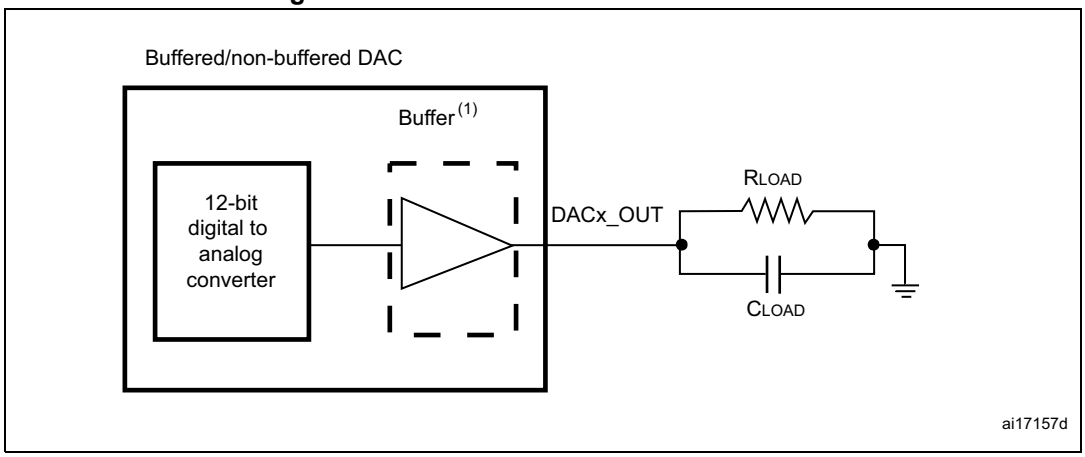
Symbol	Parameter		Min	Typ	Max	Unit
-	f_{HCLK} value to guarantee proper operation of USB HS interface		30	-	-	MHz
F_{START_8BIT}	Frequency (first transition)	8-bit ±10%	54	60	66	MHz
F_{STEADY}	Frequency (steady state) ±500 ppm		59.97	60	60.03	MHz
D_{START_8BIT}	Duty cycle (first transition)	8-bit ±10%	40	50	60	%
D_{STEADY}	Duty cycle (steady state) ±500 ppm		49.975	50	50.025	%
t_{STEADY}	Time to reach the steady state frequency and duty cycle after the first transition		-	-	1.4	ms

Table 85. DAC characteristics (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit	Comments
INL(4)	Integral non linearity (difference between measured value at Code i and the value at Code i on a line drawn between Code 0 and last Code 1023)	-	-	-	±1	LSB	Given for the DAC in 10-bit configuration.
		-	-	-	±4	LSB	Given for the DAC in 12-bit configuration.
Offset(4)	Offset error (difference between measured value at Code (0x800) and the ideal value = $V_{REF+}/2$)	-	-	-	±10	mV	Given for the DAC in 12-bit configuration
		-	-	-	±3	LSB	Given for the DAC in 10-bit at V_{REF+} = 3.6 V
		-	-	-	±12	LSB	Given for the DAC in 12-bit at V_{REF+} = 3.6 V
Gain error(4)	Gain error	-	-	-	±0.5	%	Given for the DAC in 12-bit configuration
$t_{SETTLING}$(4)	Total Harmonic Distortion Buffer ON	-	-	3	6	µs	$C_{LOAD} \leq 50$ pF, $R_{LOAD} \geq 5$ kΩ
THD(4)	-	-	-	-	-	dB	$C_{LOAD} \leq 50$ pF, $R_{LOAD} \geq 5$ kΩ
Update rate(2)	Max frequency for a correct DAC_OUT change when small variation in the input code (from code i to i+1LSB)	-	-	-	1	MS/s	$C_{LOAD} \leq 50$ pF, $R_{LOAD} \geq 5$ kΩ
t_{WAKEUP}(4)	Wakeup time from off state (Setting the ENx bit in the DAC Control register)	-	-	6.5	10	µs	$C_{LOAD} \leq 50$ pF, $R_{LOAD} \geq 5$ kΩ input code between lowest and highest possible ones.
PSRR+ (2)	Power supply rejection ratio (to V_{DDA}) (static DC measurement)	-	-	- 67	- 40	dB	No R_{LOAD}, C_{LOAD} = 50 pF

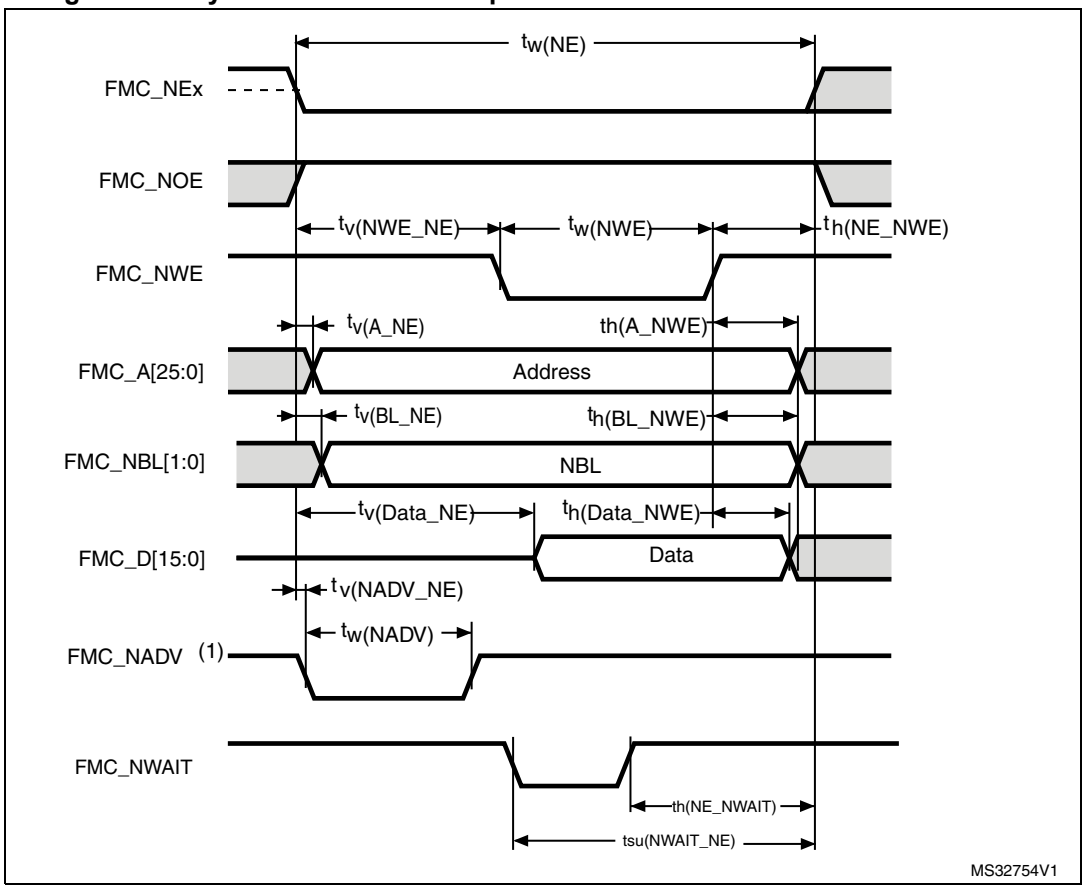
1. V_{DDA} minimum value of 1.7 V is obtained with the use of an external power supply supervisor (refer to *Section 3.16.2: Internal reset OFF*).
2. Guaranteed by design.
3. The quiescent mode corresponds to a state where the DAC maintains a stable output level to ensure that no dynamic consumption occurs.
4. Guaranteed based on test during characterization.

Figure 49. 12-bit buffered/non-buffered DAC



1. The DAC integrates an output buffer that can be used to reduce the output impedance and to drive external loads directly without the use of an external operational amplifier. The buffer can be bypassed by configuring the BOFFx bit in the DAC_CR register.

Figure 51. Asynchronous non-multiplexed SRAM/PSRAM/NOR write waveforms



1. Mode 2/B, C and D only. In Mode 1, FMC_NADV is not used.

Table 88. Asynchronous non-multiplexed SRAM/PSRAM/NOR write timings(1)(2)

Symbol	Parameter	Min	Max	Unit
$t_{w(NE)}$	FMC_NE low time	3 T_{HCLK} - 2	3 T_{HCLK} +0.5	ns
$t_{v(NWE\_NE)}$	FMC_NEx low to FMC_NWE low	T_{HCLK} – 0.5	T_{HCLK} + 0.5	
$t_{w(NWE)}$	FMC_NWE low time	T_{HCLK}	T_{HCLK}+ 0.5	
$t_{h(NE\_NWE)}$	FMC_NWE high to FMC_NE high hold time	T_{HCLK} + 0.5	-	
$t_{v(A\_NE)}$	FMC_NEx low to FMC_A valid	-	0	
$t_{h(A\_NWE)}$	Address hold time after FMC_NWE high	T_{HCLK} - 0.5	-	
$t_{v(BL\_NE)}$	FMC_NEx low to FMC_BL valid	-	1	
$t_{h(BL\_NWE)}$	FMC_BL hold time after FMC_NWE high	T_{HCLK} + 0.5	-	
$t_{v(Data\_NE)}$	Data to FMC_NEx low to Data valid	-	T_{HCLK} + 2	
$t_{h(Data\_NWE)}$	Data hold time after FMC_NWE high	T_{HCLK} + 0.5	-	
$t_{v(NADV\_NE)}$	FMC_NEx low to FMC_NADV low	-	0	
$t_{w(NADV)}$	FMC_NADV low time	-	T_{HCLK}+ 0.5	

1. C_L = 30 pF.
2. Guaranteed based on test during characterization.

Table 92. Asynchronous multiplexed PSRAM/NOR write timings(1)(2)

Symbol	Parameter	Min	Max	Unit
$t_{w(NE)}$	FMC_NE low time	$4T_{HCLK}$ - 2	$4T_{HCLK}$+0.5	ns
$t_{v(NWE\_NE)}$	FMC_NEx low to FMC_NWE low	T_{HCLK}	T_{HCLK} + 0.5	
$t_{w(NWE)}$	FMC_NWE low time	$2T_{HCLK}$	$2T_{HCLK}$ + 0.5	
$t_{h(NE\_NWE)}$	FMC_NWE high to FMC_NE high hold time	T_{HCLK}	-	
$t_{v(A\_NE)}$	FMC_NEx low to FMC_A valid	-	0	
$t_{v(NADV\_NE)}$	FMC_NEx low to FMC_NADV low	0.5	1	
$t_{w(NADV)}$	FMC_NADV low time	T_{HCLK} – 0.5	T_{HCLK}+ 0.5	
$t_{h(AD\_NADV)}$	FMC_AD(adress) valid hold time after FMC_NADV high)	T_{HCLK} – 2	-	
$t_{h(A\_NWE)}$	Address hold time after FMC_NWE high	T_{HCLK}	-	
$t_{h(BL\_NWE)}$	FMC_BL hold time after FMC_NWE high	T_{HCLK}–2	-	
$t_{v(BL\_NE)}$	FMC_NEx low to FMC_BL valid	-	2	
$t_{v(Data\_NADV)}$	FMC_NADV high to Data valid	-	T_{HCLK} + 1.5	
$t_{h(Data\_NWE)}$	Data hold time after FMC_NWE high	T_{HCLK} + 0.5	-	

1. C_L = 30 pF.
2. Guaranteed based on test during characterization.

Table 93. Asynchronous multiplexed PSRAM/NOR write-NWAIT timings(1)(2)

Symbol	Parameter	Min	Max	Unit
$t_{w(NE)}$	FMC_NE low time	$9T_{HCLK}$	$9T_{HCLK}$ + 0.5	ns
$t_{w(NWE)}$	FMC_NWE low time	$7T_{HCLK}$	$7T_{HCLK}$ + 2	
$t_{su(NWAIT\_NE)}$	FMC_NWAIT valid before FMC_NEx high	$6T_{HCLK}$ + 1.5	-	
$t_{h(NE\_NWAIT)}$	FMC_NEx hold time after FMC_NWAIT invalid	$4T_{HCLK}$ – 1	-	

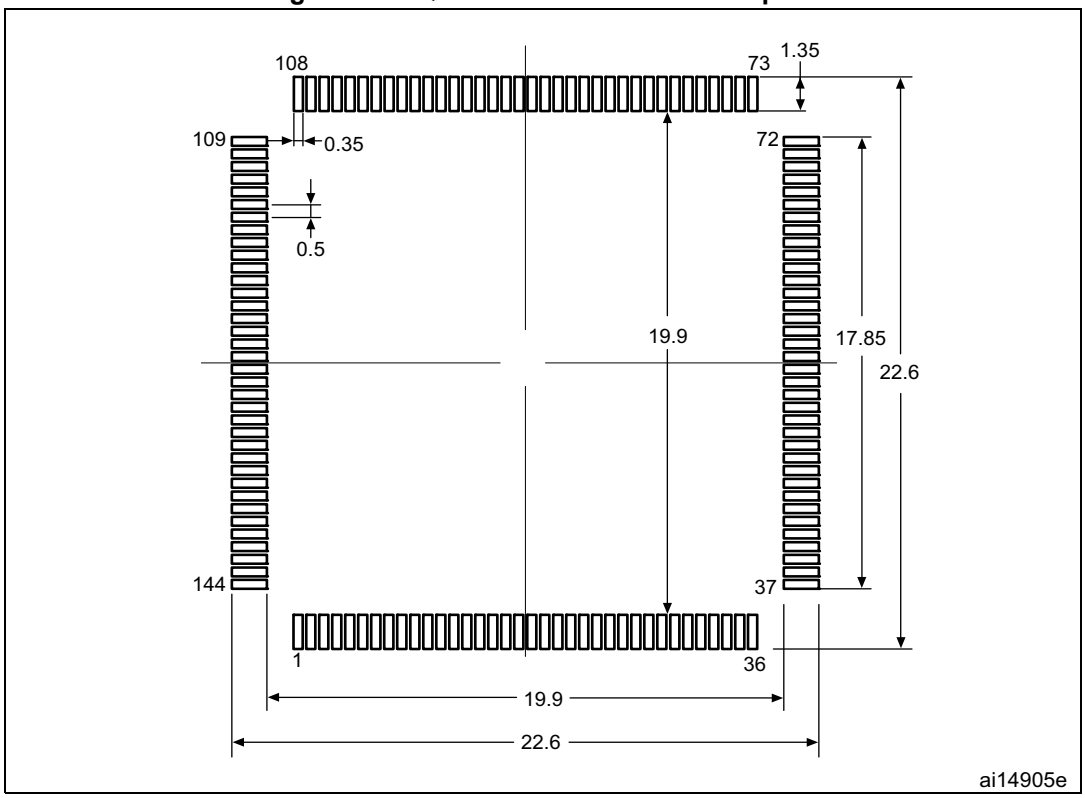
1. C_L = 30 pF.
2. Guaranteed based on test during characterization.

Synchronous waveforms and timings

Figure 54 through *Figure 57* represent synchronous waveforms and *Table 94* through *Table 97* provide the corresponding timings. The results shown in these tables are obtained with the following FMC configuration:

- BurstAccessMode = FMC_BurstAccessMode_Enable;
- MemoryType = FMC_MemoryType_CRAM;
- WriteBurst = FMC_WriteBurst_Enable;
- CLKDivision = 1; (0 is not supported, see the STM32F446 reference manual: RM0390)
- DataLatency = 1 for NOR Flash; DataLatency = 0 for PSRAM

Figure 74. LQFP144 recommended footprint



1. Dimensions are expressed in millimeters.