UM1884
User manual

Description of STM32L4/L4+ HAL and low-layer drivers

Introduction

STMCube™ is STMicroelectronics's original initiative to ease developers' life by reducing development efforts, time and cost. STM32Cube covers the STM32 portfolio.

STM32Cube Version 1.x includes:

- The STM32CubeMX, a graphical software configuration tool that allows generating C initialization code using graphical wizards.
- A comprehensive embedded software platform, delivered per series (such as STM32CubeL4 for STM32L4 series and STM32L4+ series)
  - The STM32Cube Hardware Abstraction Layer (HAL), an STM32 abstraction layer embedded software ensuring maximized portability across the STM32 portfolio. The HAL is available for all peripherals.
  - The low-layer APIs (LL) offering a fast light-weight expert-oriented layer which is closer to the hardware than the HAL. The LL APIs are available only for a set of peripherals.
  - A consistent set of middleware components such as RTOS, USB, Graphics
  - All embedded software utilities coming with a full set of examples.

The HAL driver layer provides a generic multi-instance simple set of APIs (application programming interfaces) to interact with the upper layer (application, libraries and stacks).

The HAL driver APIs are split into two categories: generic APIs which provide common and generic functions for all the STM32 series and extension APIs which include specific and customized functions for a given line or part number. The HAL drivers include a complete set of ready-to-use APIs which simplify the user application implementation. As an example, the communication peripherals contain APIs to initialize and configure the peripheral, manage data transfers in polling mode, handle interrupts or DMA, and manage communication errors.

The HAL drivers are feature-oriented instead of IP-oriented. As an example, the timer APIs are split into several categories following the IP functions: basic timer, capture, pulse width modulation (PWM), etc..

The HAL driver layer implements run-time failure detection by checking the input values of all functions. Such dynamic checking contributes to enhance the firmware robustness. Run-time detection is also suitable for user application development and debugging.

The LL drivers offer hardware services based on the available features of the STM32 peripherals. These services reflect exactly the hardware capabilities and provide atomic operations that must be called following the programming model described in the product line reference manual. As a result, the LL services are not based on standalone processes and do not require any additional memory resources to save their states, counter or data pointers: all operations are performed by changing the associated peripheral registers content. Contrary to the HAL, the LL APIs are not provided for peripherals for which optimized access is not a key feature, or for those requiring heavy software configuration and/or complex upper level stack (such as FSMC, USB, SDMMC).

The HAL and LL are complementary and cover a wide range of applications requirements:

- The HAL offers high-level and feature-oriented APIs, with a high-portability level. They hide the MCU and peripheral complexity to end-user.
- The LL offers low-level APIs at registers level, with better optimization but less portability. They require deep knowledge of the MCU and peripherals specifications.

The source code of HAL and LL drivers is developed in Strict ANSI-C which makes it independent from the development tools. It is checked with CodeSonar™ static analysis tool. It is fully documented and is MISRA-C 2004 compliant.

Contents

List of tables

List of figures

1 Acronyms and definitions

Table 1: Acronyms and definitions

Acronym	Definition
ADC	Analog-to-digital converter
AES	Advanced encryption standard
ANSI	American National Standards Institute
API	Application Programming Interface
BSP	Board Support Package
CAN	Controller area network
CMSIS	Cortex Microcontroller Software Interface Standard
COMP	Comparator
CPU	Central Processing Unit
CRC	CRC calculation unit
CSS	Clock security system
DAC	Digital to analog converter
DFSDM	Digital filter sigma delta modulator
DMA	Direct Memory Access
EXTI	External interrupt/event controller
FLASH	Flash memory
FMC	Flexible memory controller
FW	Firewall
GPIO	General purpose I/Os
HAL	Hardware abstraction layer
HCD	USB Host Controller Driver
I2C	Inter-integrated circuit
I2S	Inter-integrated sound
IRDA	InfraRed Data Association
IWDG	Independent watchdog
LCD	Liquid Crystal Display Controler
LPTIM	Low-power timer
LPUART	Low-power universal asynchronous receiver/transmitter
MCO	Microcontroller clock output
MPU	Memory protection unit
MSP	MCU Specific Package
NAND	NAND Flash memory
NOR	Nor Flash memory
NVIC	Nested Vectored Interrupt Controller

Acronym	Definition
OPAMP	Operational amplifier
OTG-FS	USB on-the-go full-speed
PCD	USB Peripheral Controller Driver
PWR	Power controller
QSPI	QuadSPI Flash memory
RCC	Reset and clock controller
RNG	Random number generator
RTC	Real-time clock
SAI	Serial audio interface
SD	Secure Digital
SDMMC	SD/SDIO/MultiMediaCard card host interface
SRAM	SRAM external memory
SMARTCARD	Smartcard IC
SPI	Serial Peripheral interface
SWPMI	Serial Wire Protocol master interface
SysTick	System tick timer
TIM	Advanced-control, general-purpose or basic timer
TSC	Touch sensing controller
UART	Universal asynchronous receiver/transmitter
USART	Universal synchronous receiver/transmitter
WWDG	Window watchdog
USB	Universal Serial Bus
PPP	STM32 peripheral or block

2 Overview of HAL drivers

The HAL drivers are designed to offer a rich set of APIs and to interact easily with the application upper layers.

Each driver consists of a set of functions covering the most common peripheral features. The development of each driver is driven by a common API which standardizes the driver structure, the functions and the parameter names.

The HAL drivers include a set of driver modules, each module being linked to a standalone peripheral. However, in some cases, the module is linked to a peripheral functional mode. As an example, several modules exist for the USART peripheral: UART driver module, USART driver module, SMARTCARD driver module and IRDA driver module.

The HAL main features are the following:

- Cross-family portable set of APIs covering the common peripheral features as well as extension APIs in case of specific peripheral features.
- Three API programming models: polling, interrupt and DMA.
- APIs are RTOS compliant:
  - Fully reentrant APIs
  - Systematic usage of timeouts in polling mode.
- Support of peripheral multi-instance allowing concurrent API calls for multiple instances of a given peripheral (USART1, USART2...)
- All HAL APIs implement user-callback functions mechanism:
  - Peripheral Init/DeInit HAL APIs can call user-callback functions to perform peripheral system level Initialization/De-Initialization (clock, GPIOs, interrupt, DMA)
  - Peripherals interrupt events
  - Error events.
- Object locking mechanism: safe hardware access to prevent multiple spurious accesses to shared resources.
- Timeout used for all blocking processes: the timeout can be a simple counter or a timebase.

2.1 HAL and user-application files

2.1.1 HAL driver files

A HAL drivers are composed of the following set of files:

Table 2: HAL driver files

File	Description
stm32l4xx_hal_ppp.c	Main peripheral/module driver file. It includes the APIs that are common to all STM32 devices. *Example: stm32l4xx_hal_adc.c, stm32l4xx_hal_irda.c, …*
stm32l4xx_hal_ppp.h	Header file of the main driver C file It includes common data, handle and enumeration structures, define statements and macros, as well as the exported generic APIs. *Example: stm32l4xx_hal_adc.h, stm32l4xx_hal_irda.h, …*

File	Description
stm32l4xx_hal_ppp_ex.c	Extension file of a peripheral/module driver. It includes the specific APIs for a given part number or family, as well as the newly defined APIs that overwrite the default generic APIs if the internal process is implemented in different way. *Example: stm32l4xx_hal_adc_ex.c, stm32l4xx_hal_flash_ex.c, …*
stm32l4xx_hal_ppp_ex.h	Header file of the extension C file. It includes the specific data and enumeration structures, define statements and macros, as well as the exported device part number specific APIs *Example: stm32l4xx_hal_adc_ex.h, stm32l4xx_hal_flash_ex.h, …*
stm32l4xx_hal.c	This file is used for HAL initialization and contains DBGMCU, Remap and Time Delay based on SysTick APIs.
stm32l4xx_hal.h	*stm32l4*xx_hal.c header file
stm32l4xx_hal_msp_template.c	Template file to be copied to the user application folder. It contains the MSP initialization and de-initialization (main routine and callbacks) of the peripheral used in the user application.
stm32l4xx_hal_conf_template.h	Template file allowing to customize the drivers for a given application.
stm32l4xx_hal_def.h	Common HAL resources such as common define statements, enumerations, structures and macros.

2.1.2 User-application files

The minimum files required to build an application using the HAL are listed in the table below:

Table 3: User-application files

File	Description
system_stm32l4xx.c	This file contains SystemInit() which is called at startup just after reset and before branching to the main program. It does not configure the system clock at startup (contrary to the standard library). This is to be done using the HAL APIs in the user files. It allows relocating the vector table in internal SRAM.
startup_stm32l4xx.s	Toolchain specific file that contains reset handler and exception vectors. For some toolchains, it allows adapting the stack/heap size to fit the application requirements.
stm32l4xx_flash.icf (optional)	Linker file for EWARM toolchain allowing mainly adapting the stack/heap size to fit the application requirements.
stm32l4xx_hal_msp.c	This file contains the MSP initialization and de-initialization (main routine and callbacks) of the peripheral used in the user application.
stm32l4xx_hal_conf.h	This file allows the user to customize the HAL drivers for a specific application. It is not mandatory to modify this configuration. The application can use the default configuration without any modification.

File	Description
stm32l4xx_it.c/.h	This file contains the exceptions handler and peripherals interrupt service routine, and calls HAL_IncTick() at regular time intervals to increment a local variable (declared in *stm32l4x*x_hal.c) used as HAL timebase. By default, this function is called each 1ms in Systick ISR. . The PPP_IRQHandler() routine must call HAL_PPP_IRQHandler() if an interrupt based process is used within the application.
main.c/.h	This file contains the main program routine, mainly: • the call to HAL_Init() • assert_failed() implementation • system clock configuration • peripheral HAL initialization and user application code.

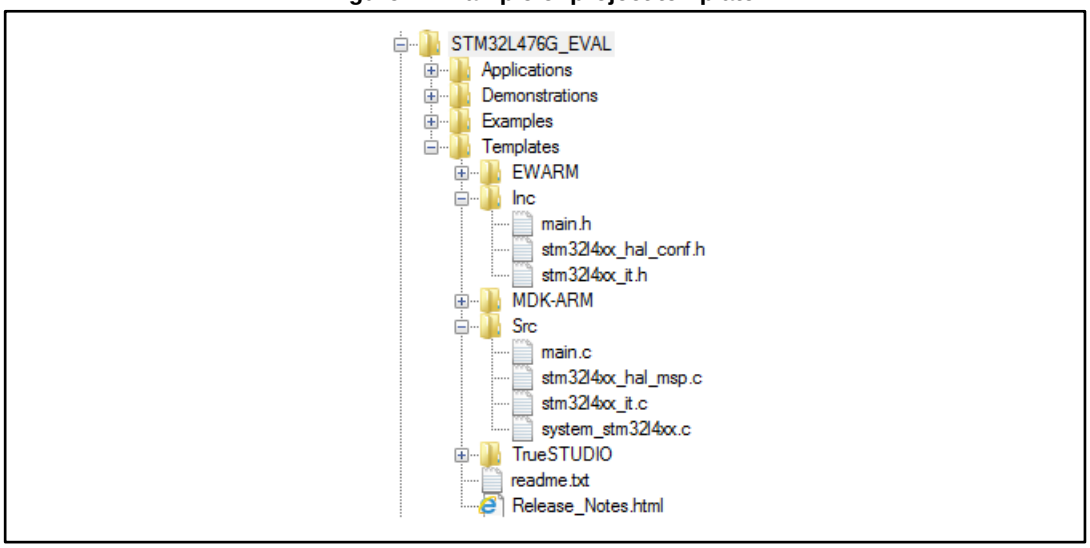
The STM32Cube package comes with ready-to-use project templates, one for each supported board. Each project contains the files listed above and a preconfigured project for the supported toolchains.

Each project template provides empty main loop function and can be used as a starting point to get familiar with project settings for STM32Cube. Its features are the following:

- It contains the sources of HAL, CMSIS and BSP drivers which are the minimal components to develop a code on a given board.
- It contains the include paths for all the firmware components.
- It defines the STM32 device supported, and allows configuring the CMSIS and HAL drivers accordingly.
- It provides ready to use user files preconfigured as defined below:
  – HAL is initialized
  – SysTick ISR implemented for HAL_GetTick()
  – System clock configured with the selected device frequency.

If an existing project is copied to another location, then include paths must be updated.

Figure 1: Example of project template



2.2 HAL data structures

Each HAL driver can contain the following data structures:

- Peripheral handle structures
- Initialization and configuration structures
- Specific process structures.

2.2.1 Peripheral handle structures

The APIs have a modular generic multi-instance architecture that allows working with several IP instances simultaneously.

PPP_HandleTypeDef *handle is the main structure that is implemented in the HAL drivers. It handles the peripheral/module configuration and registers and embeds all the structures and variables needed to follow the peripheral device flow.

The peripheral handle is used for the following purposes:

- Multi instance support: each peripheral/module instance has its own handle. As a result instance resources are independent.
- Peripheral process intercommunication: the handle is used to manage shared data resources between the process routines.
  Example: global pointers, DMA handles, state machine.
- Storage: this handle is used also to manage global variables within a given HAL driver.

An example of peripheral structure is shown below:

```
typedef struct
{
USART TypeDef *Instance; /* USART registers base address */
USART InitTypeDef Init; /* Usart communication parameters */
uint8_t *pTxBuffPtr;/* Pointer to Usart Tx transfer Buffer */
uint16_t TxXferSize; /* Usart Tx Transfer size */
__IO uint16_t TxXferCount;/* Usart Tx Transfer Counter */
uint8 t *pRxBuffPtr;/* Pointer to Usart Rx transfer Buffer */
uint16 t RxXferSize; /* Usart Rx Transfer size */
  IO uint16 t RxXferCount; /* Usart Rx Transfer Counter */
DMA_HandleTypeDef *hdmatx; /* Usart Tx DMA Handle parameters */
DMA_HandleTypeDef *hdmarx; /* Usart Rx DMA Handle parameters */
HAL_LockTypeDef Lock; /* Locking object */
  IO HAL USART StateTypeDef State; /* Usart communication state */
  IO HAL USART ErrorTypeDef ErrorCode;/* USART Error code */
}USART_HandleTypeDef;
```

1) The multi-instance feature implies that all the APIs used in the application are re-entrant and avoid using global variables because subroutines can fail to be re-entrant if they rely on a global variable to remain unchanged but that variable is modified when the subroutine is recursively invoked. For this reason, the following rules are respected:

- Re-entrant code does not hold any static (or global) non-constant data: re-entrant functions can work with global data. For example, a re-entrant interrupt service routine can grab a piece of hardware status to work with (e.g. serial port read buffer) which is not only global, but volatile. Still, typical use of static variables and global data is not advised, in the sense that only atomic read-modify-write instructions should be used in these variables. It should not be possible for an interrupt or signal to occur during the execution of such an instruction.
- Reentrant code does not modify its own code.

2) When a peripheral can manage several processes simultaneously using the DMA (full duplex case), the DMA interface handle for each process is added in the PPP_HandleTypeDef.

3) For the shared and system peripherals, no handle or instance object is used. The peripherals concerned by this exception are the following:

- GPIO
- SYSTICK
- NVIC
- PWR
- RCC
- FLASH.

2.2.2 Initialization and configuration structure

These structures are defined in the generic driver header file when it is common to all part numbers. When they can change from one part number to another, the structures are defined in the extension header file for each part number.

```
typedef struct
{
uint32 t BaudRate; /*!< This member configures the UART communication baudrate.*/
uint32_t WordLength; /*!< Specifies the number of data bits transmitted or received
in a frame.*/
uint32_t StopBits; /*!< Specifies the number of stop bits transmitted.*/
uint32_t Parity; /*!< Specifies the parity mode. */
uint32 t Mode; /*!< Specifies wether the Receive or Transmit mode is enabled or
disabled.*/
uint32_t HwFlowCtl; /*!< Specifies wether the hardware flow control mode is enabled
or disabled.*/
uint32 t OverSampling; /*!< Specifies wether the Over sampling 8 is enabled or
disabled,
to achieve higher speed (up to fPCLK/8).*/
}UART_InitTypeDef;
```

The config structure is used to initialize the sub-modules or sub-instances. See below example:

```
HAL_ADC_ConfigChannel (ADC_HandleTypeDef* hadc, ADC_ChannelConfTypeDef*
sConfig)
```

2.2.3 Specific process structures

The specific process structures are used for specific process (common APIs). They are defined in the generic driver header file.

Example:

```
HAL_PPP_Process (PPP_HandleTypeDef* hadc,PPP_ProcessConfig* sConfig)
```

2.3 API classification

The HAL APIs are classified into three categories:

- **Generic APIs:** common generic APIs applying to all STM32 devices. These APIs are consequently present in the generic HAL driver files of all STM32 microcontrollers.

```
HAL StatusTypeDef HAL ADC Init(ADC HandleTypeDef* hadc); HAL StatusTypeDef
HAL ADC DeInit(ADC HandleTypeDef *hadc); HAL StatusTypeDef
HAL ADC Start(ADC HandleTypeDef* hadc); HAL StatusTypeDef
HAL_ADC_Stop(ADC_HandleTypeDef* hadc); HAL_StatusTypeDef
HAL_ADC_Start_IT(ADC_HandleTypeDef* hadc); HAL_StatusTypeDef
HAL ADC Stop IT(ADC HandleTypeDef* hadc); void HAL ADC IRQHandler(ADC HandleTypeDef*
hadc);
```

- **Extension APIs:** This set of API is divided into two sub-categories:
  - **Family specific APIs:** APIs applying to a given family. They are located in the extension HAL driver file (see example below related to the ADC).

```
HAL StatusTypeDef HAL ADCEx Calibration Start(ADC HandleTypeDef* hadc, uint32 t
SingleDiff);
uint32_t HAL_ADCEx_Calibration_GetValue(ADC_HandleTypeDef* hadc, uint32_t
SingleDiff);
```

  - **Device part number specific APIs:** These APIs are implemented in the extension file and delimited by specific define statements relative to a given part number.

```
#if defined(STM32L475xx) || defined(STM32L476xx)|| defined(STM32L486xx)
void HAL PWREx EnableVddUSB(void);
void HAL PWREx DisableVddUSB(void);
#endif /* STM32L475xx || STM32L476xx || STM32L486xx */
```

The data structure related to the specific APIs is delimited by the device part number define statement. It is located in the corresponding extension header C file.

The following table summarizes the location of the different categories of HAL APIs in the driver files.

Table 4: API classification

	Generic file	Extension file
Common APIs	X	X
Family specific APIs		X
Device specific APIs		X

Family specific APIs are only related to a given family. This means that if a specific API is implemented in another family, and the arguments of this latter family are different, additional structures and arguments might need to be added.

The IRQ handlers are used for common and family specific processes.

2.4 Devices supported by HAL drivers

Table 5: List of STM32L4 Series devices supported by HAL drivers

IP/ Module	STM32L431xx	STM32L432xx	STM32L442xx	STM32L433xx	STM32L443xx	STM32L451xx	STM32L452xx	STM32L462xx	STM32L471xx	STM32L475xx	STM32L476xx	STM32L485xx	STM32L486xx	STM32L496xx	STM32L4A6xx
stm32l4xx_hal.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_adc.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_adc_ex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_can.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_comp.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_cortex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_crc.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_crc_ex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_cryp.c	No	No	Yes	No	Yes	No	No	Yes	No	No	No	Yes	Yes	No	Yes
stm32l4xx_hal_cryp_ex.c	No	No	Yes	No	Yes	No	No	Yes	No	No	No	Yes	Yes	No	Yes
stm32l4xx_hal_dac.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_dac_ex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_dcmi.c	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes
stm32l4xx_hal_dfsdm.c	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_dfsdm_ex.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
stm32l4xx_hal_dma.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_dma_ex.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
stm32l4xx_hal_dma2d.c	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes
stm32l4xx_hal_dsi.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
stm32l4xx_hal_firewall.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_flash.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_flash_ex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

IP/ Module	STM32L431xx	STM32L432xx	STM32L442xx	STM32L433xx	STM32L443xx	STM32L451xx	STM32L452xx	STM32L462xx	STM32L471xx	STM32L475xx	STM32L476xx	STM32L485xx	STM32L486xx	STM32L496xx	STM32L4A6xx
stm32l4xx_hal_flash_ramfunc.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_gfxmmu.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
stm32l4xx_hal_gpio.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_hash.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes
stm32l4xx_hal_hash_ex.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes
stm32l4xx_hal_hcd.c	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_i2c.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_i2c_ex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_irda.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_iwdg.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_lcd.c	No	No	No	Yes	Yes	No	No	No	No	No	Yes	No	Yes	Yes	Yes
stm32l4xx_hal_lptim.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_ltdc.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
stm32l4xx_hal_ltdc_ex.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
stm32l4xx_hal_msp_template.c	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
stm32l4xx_hal_nand.c	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_nor.c	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_opamp.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_opamp_ex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_ospi.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
stm32l4xx_hal_pcd.c	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_pcd_ex.c	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_pwr.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

IP/ Module	STM32L431xx	STM32L432xx	STM32L442xx	STM32L433xx	STM32L443xx	STM32L451xx	STM32L452xx	STM32L462xx	STM32L471xx	STM32L475xx	STM32L476xx	STM32L485xx	STM32L486xx	STM32L496xx	STM32L4A6xx
stm32l4xx_hal_pwr_ex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_qspi.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_rcc.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_rcc_ex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_rng.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_rtc.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_rtc_ex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_sai.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_sai_ex.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
stm32l4xx_hal_sd.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_sd_ex.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
stm32l4xx_hal_smartcard.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_smartcard_ex.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
stm32l4xx_hal_smbus.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_spi.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_spi_ex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_sram.c	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_swpmi.c	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_tim.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_tim_ex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_tsc.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_uart.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_uart_ex.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

IP/ Module	STM32L431xx	STM32L432xx	STM32L442xx	STM32L433xx	STM32L443xx	STM32L451xx	STM32L452xx	STM32L462xx	STM32L471xx	STM32L475xx	STM32L476xx	STM32L485xx	STM32L486xx	STM32L496xx	STM32L4A6xx
stm32l4xx_hal_usart.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_usart_ex.c	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
stm32l4xx_hal_wwdg.c	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 6: List of STM32L4+ Series devices supported by HAL drivers

IP/Module	STM32L4R5xx	STM32L4R7xx	STM32L4R9xx	STM32L4S5xx	STM32L4S7xx	STM32L4S9xx
stm32l4xx_hal.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_adc.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_adc_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_can.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_comp.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_cortex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_crc.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_crc_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_cryp.c	No	No	No	Yes	Yes	Yes
stm32l4xx_hal_cryp_ex.c	No	No	No	Yes	Yes	Yes
stm32l4xx_hal_dac.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_dac_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_dcmi.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_dfsdm.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_dfsdm_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_dma.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_dma_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_dma2d.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_dsi.c	No	No	Yes	No	No	Yes
stm32l4xx_hal_firewall.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_flash.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_flash_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_flash_ramfunc.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_gfxmmu.c	No	Yes	Yes	No	Yes	Yes
stm32l4xx_hal_gpio.c	Yes	Yes	Yes	Yes	Yes	Yes

IP/Module	STM32L4R5xx	STM32L4R7xx	STM32L4R9xx	STM32L4S5xx	STM32L4S7xx	STM32L4S9xx
stm32l4xx_hal_hash.c	No	No	No	Yes	Yes	Yes
stm32l4xx_hal_hash_ex.c	No	No	No	Yes	Yes	Yes
stm32l4xx_hal_hcd.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_i2c.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_i2c_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_irda.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_iwdg.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_lcd.c	No	No	No	No	No	No
stm32l4xx_hal_lptim.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_ltdc.c	No	Yes	Yes	No	Yes	Yes
stm32l4xx_hal_ltdc_ex.c	No	Yes	Yes	No	Yes	Yes
stm32l4xx_hal_msp_template.c	NA	NA	NA	NA	NA	NA
stm32l4xx_hal_nand.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_nor.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_opamp.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_opamp_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_ospi.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_pcd.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_pcd_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_pwr.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_pwr_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_qspi.c	No	No	No	No	No	No
stm32l4xx_hal_rcc.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_rcc_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_rng.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_rtc.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_rtc_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_sai.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_sai_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_sd.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_sd_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_smartcard.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_smartcard_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_smbus.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_spi.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_spi_ex.c	Yes	Yes	Yes	Yes	Yes	Yes

IP/Module	STM32L4R5xx	STM32L4R7xx	STM32L4R9xx	STM32L4S5xx	STM32L4S7xx	STM32L4S9xx
stm32l4xx_hal_sram.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_swpmi.c	No	No	No	No	No	No
stm32l4xx_hal_tim.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_tim_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_tsc.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_uart.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_uart_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_usart.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_usart_ex.c	Yes	Yes	Yes	Yes	Yes	Yes
stm32l4xx_hal_wwdg.c	Yes	Yes	Yes	Yes	Yes	Yes

2.5 HAL driver rules

2.5.1 HAL API naming rules

The following naming rules are used in HAL drivers:

Table 7: HAL API naming rules

	Generic	Family specific	Device specific
File names	*stm32l4xx_hal_ppp (c/h)*	*stm32l4xx_hal_ppp_ex (c/h)*	*stm32l4xx_ hal_ppp_ex (c/h)*
Module name	*HAL_PPP_ MODULE*		
Function name	*HAL_PPP_Function HAL_PPP_FeatureFunction_ MODE*	*HAL_PPPEx_Function HAL_PPPEx_FeatureFunction_M ODE*	*HAL_PPPEx_Function HAL_PPPEx_FeatureFunction_M ODE*
Handle name	*PPP_HandleTypedef*	*NA*	*NA*
Init structure name	*PPP_InitTypeDef*	*NA*	*PPP_InitTypeDef*
Enum name	*HAL_PPP_StructnameType Def*	*NA*	*NA*

- The **PPP** prefix refers to the peripheral functional mode and not to the peripheral itself. For example, if the USART, PPP can be USART, IRDA, UART or SMARTCARD depending on the peripheral mode.
- The constants used in one file are defined within this file. A constant used in several files is defined in a header file. All constants are written in uppercase, except for peripheral driver function parameters.
- typedef variable names should be suffixed with _TypeDef.

- Registers are considered as constants. In most cases, their name is in uppercase and uses the same acronyms as in the STM32L4 series and STM32L4+ series reference manuals.
- Peripheral registers are declared in the PPP_TypeDef structure (e.g. ADC_TypeDef) in stm32l4xxx.h header file.stm32l4xxx.h corresponds to stm32l471xx.h,stm32l475xx.h, stm32l476xx, stm32l485xx and stm32l486xx.h.
- Peripheral function names are prefixed by HAL_, then the corresponding peripheral acronym in uppercase followed by an underscore. The first letter of each word is in uppercase (e.g. HAL_UART_Transmit()). Only one underscore is allowed in a function name to separate the peripheral acronym from the rest of the function name.
- The structure containing the PPP peripheral initialization parameters are named PPP_InitTypeDef (e.g. ADC_InitTypeDef).
- The structure containing the Specific configuration parameters for the PPP peripheral are named PPP_xxxxConfTypeDef (e.g. ADC_ChannelConfTypeDef).
- Peripheral handle structures are named PPP_HandleTypedef (e.g DMA_HandleTypeDef)
- The functions used to initialize the PPP peripheral according to parameters specified in PPP_InitTypeDef are named HAL_PPP_Init (e.g. HAL_TIM_Init()).
- The functions used to reset the PPP peripheral registers to their default values are named HAL_PPP_DeInit (e.g. HAL_TIM_DeInit()).
- The **MODE** suffix refers to the process mode, which can be polling, interrupt or DMA. As an example, when the DMA is used in addition to the native resources, the function should be called: *HAL_PPP_Function_DMA ()*.
- The **Feature** prefix should refer to the new feature.
  Example: *HAL_ADCEx_InjectedStart()*() refers to the injection mode

2.5.2 HAL general naming rules

- For the shared and system peripherals, no handle or instance object is used. This rule applies to the following peripherals:
  – GPIO
  – SYSTICK
  – NVIC
  – RCC
  – FLASH.

Example: The *HAL_GPIO_Init()* requires only the GPIO address and its configuration parameters.

```
HAL_StatusTypeDef HAL_GPIO_Init (GPIO_TypeDef* GPIOx, GPIO_InitTypeDef *Init)
{
/*GPIO Initialization body */
}
```

- The macros that handle interrupts and specific clock configurations are defined in each peripheral/module driver. These macros are exported in the peripheral driver header files so that they can be used by the extension file. The list of these macros is defined below: This list is not exhaustive and other macros related to peripheral features can be added, so that they can be used in the user application.

Table 8: Macros handling interrupts and specific clock configurations

Macros	Description
__HAL_PPP_ENABLE_IT(__HANDLE__, __INTERRUPT__)	Enables a specific peripheral interrupt
__HAL_PPP_DISABLE_IT(__HANDLE__, __INTERRUPT__)	Disables a specific peripheral interrupt
__HAL_PPP_GET_IT (__HANDLE__, __ INTERRUPT __)	Gets a specific peripheral interrupt status
__HAL_PPP_CLEAR_IT (__HANDLE__, __ INTERRUPT __)	Clears a specific peripheral interrupt status
__HAL_PPP_GET_FLAG (__HANDLE__, __FLAG__)	Gets a specific peripheral flag status
__HAL_PPP_CLEAR_FLAG (__HANDLE__, __FLAG__)	Clears a specific peripheral flag status
__HAL_PPP_ENABLE(__HANDLE__)	Enables a peripheral
__HAL_PPP_DISABLE(__HANDLE__)	Disables a peripheral
__HAL_PPP_XXXX (__HANDLE__, __PARAM__)	Specific PPP HAL driver macro
__HAL_PPP_GET_ IT_SOURCE (__HANDLE__, __ INTERRUPT __)	Checks the source of specified interrupt

- NVIC and SYSTICK are two Arm Cortex core features. The APIs related to these features are located in the stm32l4xx_hal_cortex.c file.
- When a status bit or a flag is read from registers, it is composed of shifted values depending on the number of read values and of their size. In this case, the returned status width is 32 bits. Example: STATUS = XX | (YY << 16) or STATUS = XX | (YY << 8) | (YY << 16) | (YY << 24)".
- The PPP handles are valid before using the HAL_PPP_Init() API. The init function performs a check before modifying the handle fields.

```
HAL_PPP_Init(PPP_HandleTypeDef) if(hppp == NULL) { return HAL_ERROR; }
```

- The macros defined below are used:
  - Conditional macro:

```
#define ABS(x) (((x) > 0) ? (x): -(x))
```

  - Pseudo-code macro (multiple instructions macro):

```
#define __HAL_LINKDMA(__HANDLE__, __PPP_DMA_FIELD_, __DMA_HANDLE_) \µ
 do{ \ (  HANDLE  )->  PPP DMA FIELD  = &(  DMA HANDLE ); \
 (__DMA_HANDLE_).Parent = (__HANDLE__); \
 } while(0)
```

2.5.3 HAL interrupt handler and callback functions

Besides the APIs, HAL peripheral drivers include:

- HAL_PPP_IRQHandler() peripheral interrupt handler that should be called from stm32l4xx_it.c
- User callback functions.

The user callback functions are defined as empty functions with “weak” attribute. They have to be defined in the user code.

There are three types of user callbacks functions:

- Peripheral system level initialization/ de-Initialization callbacks: HAL_PPP_MspInit() and HAL_PPP_MspDeInit
- Process complete callbacks: HAL_PPP_ProcessCpltCallback
- Error callback: HAL_PPP_ErrorCallback.

Table 9: Callback functions

Callback functions	Example
HAL_PPP_MspInit() / _DeInit()	Ex: HAL_USART_MspInit() Called from HAL_PPP_Init() API function to perform peripheral system level initialization (GPIOs, clock, DMA, interrupt)
HAL_PPP_ProcessCpltCallback	Ex: HAL_USART_TxCpltCallback Called by peripheral or DMA interrupt handler when the process completes
HAL_PPP_ErrorCallback	Ex: HAL_USART_ErrorCallback Called by peripheral or DMA interrupt handler when an error occurs

2.6 HAL generic APIs

The generic APIs provide common generic functions applying to all STM32 devices. They are composed of four APIs groups:

- **Initialization and de-initialization functions:**HAL_PPP_Init(), HAL_PPP_DeInit()
- **IO operation functions**: HAL_PPP_Read(), HAL_PPP_Write(),HAL_PPP_Transmit(), HAL_PPP_Receive()
- **Control functions**: HAL_PPP_Set (), HAL_PPP_Get ().
- **State and Errors functions**: HAL_PPP_GetState (), HAL_PPP_GetError ().

For some peripheral/module drivers, these groups are modified depending on the peripheral/module implementation.

Example: in the timer driver, the API grouping is based on timer features (PWM, OC, IC...).

The initialization and de-initialization functions allow initializing a peripheral and configuring the low-level resources, mainly clocks, GPIO, alternate functions (AF) and possibly DMA and interrupts. The *HAL_DeInit()*function restores the peripheral default state, frees the low-level resources and removes any direct dependency with the hardware.

The IO operation functions perform a row access to the peripheral payload data in write and read modes.

The control functions are used to change dynamically the peripheral configuration and set another operating mode.

The peripheral state and errors functions allow retrieving in runtime the peripheral and data flow states, and identifying the type of errors that occurred. The example below is based on the ADC peripheral. The list of generic APIs is not exhaustive. It is only given as an example.

Table 10: HAL generic APIs

Function group	Common API name	Description
Initialization group	*HAL_ADC_Init()*	This function initializes the peripheral and configures the low -level resources (clocks, GPIO, AF..)
	HAL_ADC_DeInit()	This function restores the peripheral default state, frees the low-level resources and removes any direct dependency with the hardware.
IO operation group	*HAL_ADC_Start ()*	This function starts ADC conversions when the polling method is used
	HAL_ADC_Stop ()	This function stops ADC conversions when the polling method is used
	HAL_ADC_PollForConversion()	This function allows waiting for the end of conversions when the polling method is used. In this case, a timout value is specified by the user according to the application.
	HAL_ADC_Start_IT()	This function starts ADC conversions when the interrupt method is used
	HAL_ADC_Stop_IT()	This function stops ADC conversions when the interrupt method is used
	HAL_ADC_IRQHandler()	This function handles ADC interrupt requests
	HAL_ADC_ConvCpltCallback()	Callback function called in the IT subroutine to indicate the end of the current process or when a DMA transfer has completed
	HAL_ADC_ErrorCallback()	Callback function called in the IT subroutine if a peripheral error or a DMA transfer error occurred
Control group	*HAL_ADC_ConfigChannel()*	This function configures the selected ADC regular channel, the corresponding rank in the sequencer and the sample time
	HAL_ADC_AnalogWDGConfig	This function configures the analog watchdog for the selected ADC
State and Errors group	*HAL_ADC_GetState()*	This function allows getting in runtime the peripheral and the data flow states.
	HAL_ADC_GetError()	This fuction allows getting in runtime the error that occurred during IT routine

2.7 HAL extension APIs

2.7.1 HAL extension model overview

The extension APIs provide specific functions or overwrite modified APIs for a specific family (series) or specific part number within the same family.

The extension model consists of an additional file, stm32l4xx_hal_ppp_ex.c, that includes all the specific functions and define statements (stm32l4xx_hal_ppp_ex.h) for a given part number.

Below an example based on the ADC peripheral:

Table 11: HAL extension APIs

Function Group	Common API Name
HAL_ADCEx_CalibrationStart()	This function is used to start the automatic ADC calibration

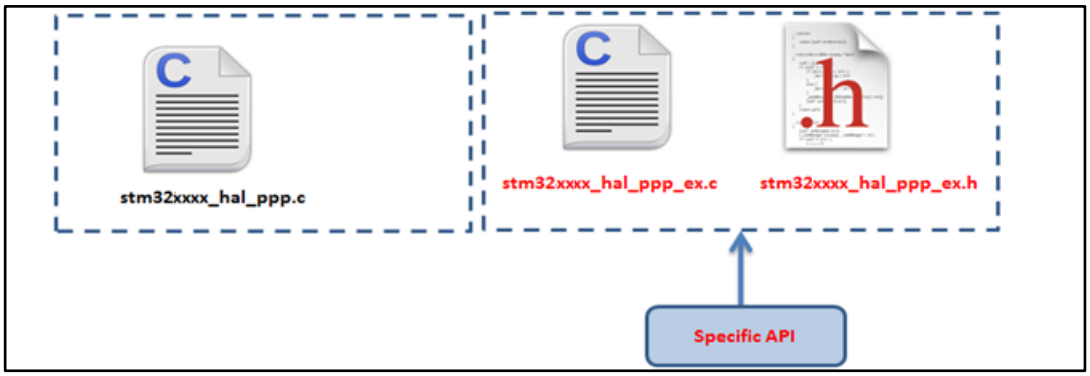
2.7.2 HAL extension model cases

The specific IP features can be handled by the HAL drivers in five different ways. They are described below.

Case 1: Adding a part number-specific function

When a new feature specific to a given device is required, the new APIs are added in the stm32l4xx_hal_ppp_ex.c extension file. They are named HAL_PPPEx_Function().

Figure 2: Adding device-specific functions



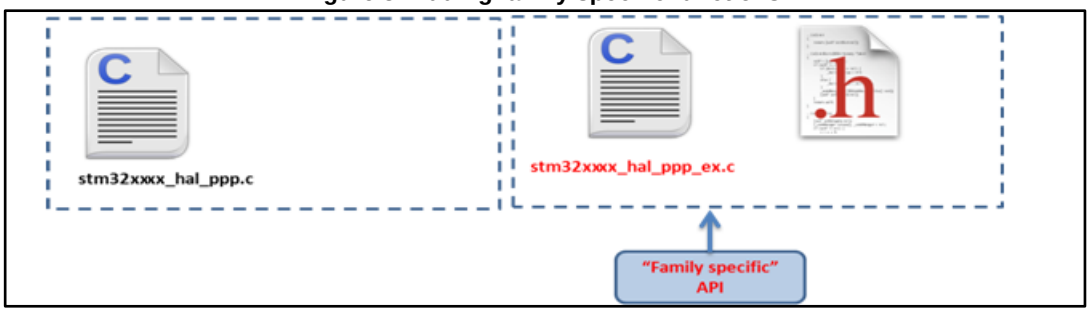
Example: stm32l4xx_hal_adc_ex.c/h

```
#if defined(STM32L475xx) || defined(STM32L476xx) || defined(STM32L486xx)
void HAL PWREx EnableVddUSB(void);
void HAL PWREx DisableVddUSB(void);
#endif /* STM32L475xx || STM32L476xx || STM32L486xx */
```

Case 2: Adding a family-specific function

In this case, the API is added in the extension driver C file and named HAL_PPPEx_Function ().

Figure 3: Adding family-specific functions

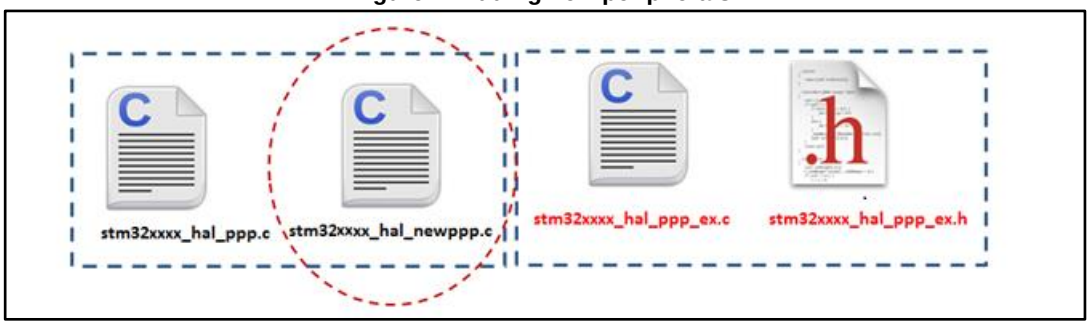


Case 3: Adding a new peripheral (specific to a device belonging to a given family)

When a peripheral which is available only in a specific device is required, the APIs corresponding to this new peripheral/module (newPPP) are added in a new stm32l4xx_hal_newppp.c. However the inclusion of this file is selected in the stm32lxx_hal_conf.h using the macro:

```
#define HAL_NEWPPP_MODULE_ENABLED
```

Figure 4: Adding new peripherals

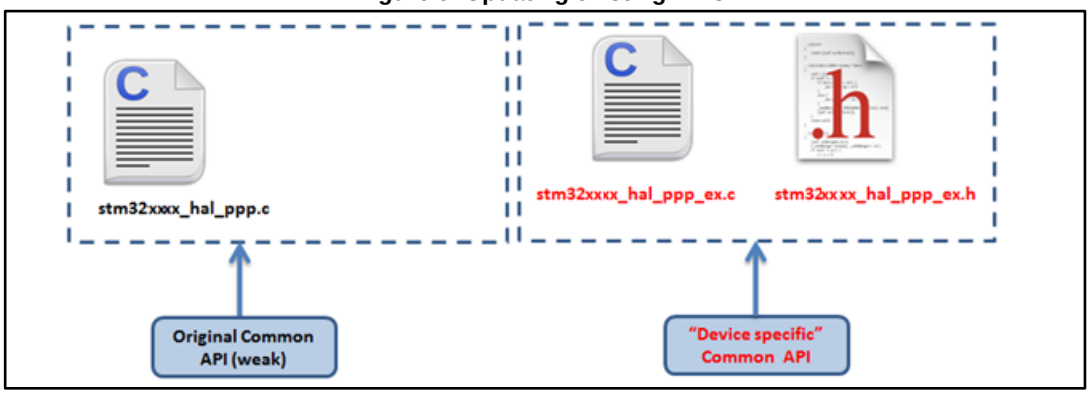


Example: stm32l4xx_hal_lcd.c/h

Case 4: Updating existing common APIs

In this case, the routines are defined with the same names in the stm32l4xx_hal_ppp_ex.c extension file, while the generic API is defined as *weak*, so that the compiler will overwrite the original routine by the new defined function.

Figure 5: Updating existing APIs



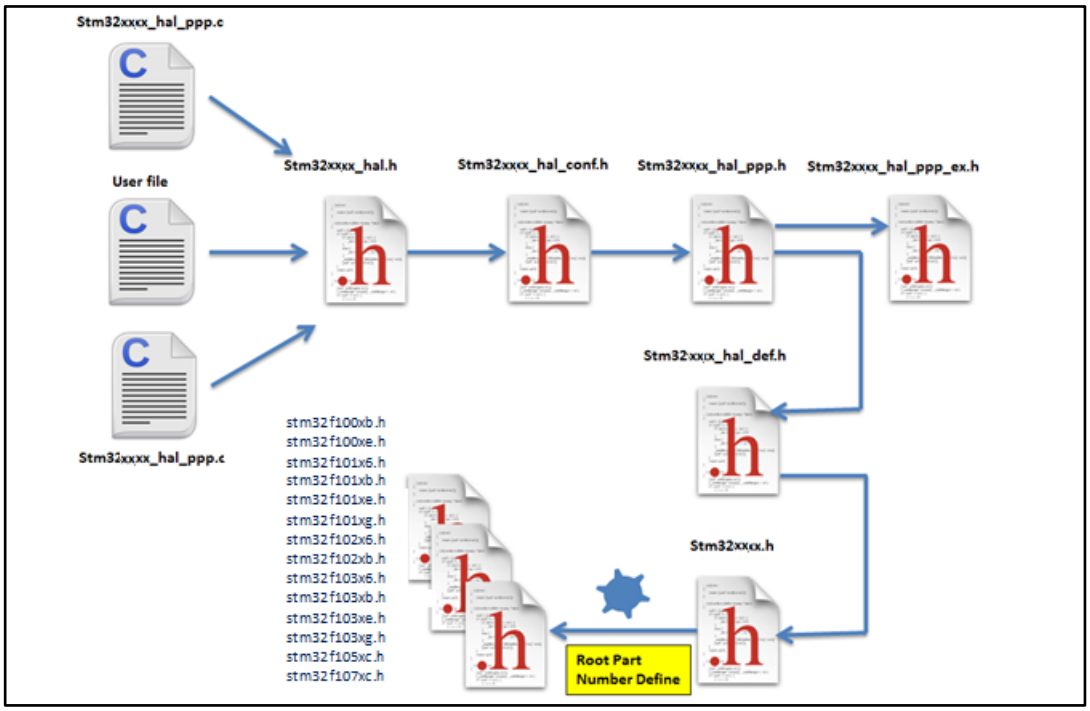
Case 5: Updating existing data structures

The data structure for a specific device part number (e.g. PPP_InitTypeDef) can have different fields. In this case, the data structure is defined in the extension header file and delimited by the specific part number define statement.

2.8 File inclusion model

The header of the common HAL driver file (stm32l4xx_hal.h) includes the common configurations for the whole HAL library. It is the only header file that is included in the user sources and the HAL C sources files to be able to use the HAL resources.

Figure 6: File inclusion model



A PPP driver is a standalone module which is used in a project. The user must enable the corresponding USE_HAL_PPP_MODULE define statement in the configuration file.

```
/**********************************************************************
* @file stm32l4xx hal conf.h
* @author MCD Application Team
* @version VX.Y.Z * @date dd-mm-yyyy
* @brief This file contains the modules to be used
**********************************************************************
(…)
#define HAL USART MODULE ENABLED
#define HAL_IRDA_MODULE_ENABLED
#define HAL_DMA_MODULE_ENABLED
#define HAL_RCC_MODULE_ENABLED
(…)
```

2.9 HAL common resources

The common HAL resources, such as common define enumerations, structures and macros, are defined in *stm32l4xx_hal_def.h.*The main common define enumeration is *HAL_StatusTypeDef*.

- **HAL Status** The HAL status is used by almost all HAL APIs, except for boolean functions and IRQ handler. It returns the status of the current API operations. It has four possible values as described below:

```
Typedef enum
{ HAL OK = 0x00, HAL ERROR = 0x01, HAL BUSY = 0x02, HAL TIMEOUT = 0x03
} HAL_StatusTypeDef;
```

- **HAL Locked** The HAL lock is used by all HAL APIs to prevent accessing by accident shared resources.

```
typedef enum
{ HAL UNLOCKED = 0x00, /*!<Resources unlocked */
HAL_LOCKED = 0x01 /*!< Resources locked */
} HAL_LockTypeDef;
```

  In addition to common resources, the stm32l4xx_hal_def.h file calls the stm32l4xx.h file in CMSIS library to get the data structures and the address mapping for all peripherals:

  – Declarations of peripheral registers and bits definition.
  – Macros to access peripheral registers hardware (Write register, Read register…etc.).

- **Common macros**
  – Macro defining HAL_MAX_DELAY

```
#define HAL_MAX_DELAY 0xFFFFFFFF
```

  – Macro linking a PPP peripheral to a DMA structure pointer:

```
#define __HAL_LINKDMA(__HANDLE__, __PPP_DMA_FIELD_, __DMA_HANDLE_) \
do{ \
(  HANDLE  )->  PPP DMA FIELD  = &(  DMA HANDLE ); \
(  DMA HANDLE ).Parent = (  HANDLE  ); \
} while(0)
```

2.10 HAL configuration

The configuration file, stm32l4xx_hal_conf.h, allows customizing the drivers for the user application. Modifying this configuration is not mandatory: the application can use the default configuration without any modification.

To configure these parameters, the user should enable, disable or modify some options by uncommenting, commenting or modifying the values of the related define statements as described in the table below:

Table 12: Define statements used for HAL configuration

Configuration item	Description	Default Value
HSE_VALUE	Defines the value of the external oscillator (HSE) expressed in Hz. The user must adjust this define statement when using a different crystal value.	8 000 000 Hz
HSE_STARTUP_TIMEOUT	Timeout for HSE start-up, expressed in ms	100

Configuration item	Description	Default Value
HSI_VALUE	Defines the value of the internal oscillator (HSI) expressed in Hz.	16 000 000 Hz
MSI_VALUE	Defines the default value of the Multiplespeed internal oscillator (MSI) expressed in Hz.	4 000 000 Hz
LSI_VALUE	Defines the default value of the Low-speed internal oscillator (LSI) expressed in Hz.	32000 Hz
LSE_VALUE	Defines the value of the external oscillator (LSE) expressed in Hz. The user must adjust this define statement when using a different crystal value.	32768 Hz
LSE_STARTUP_TIMEOUT	Timeout for LSE start-up, expressed in ms	5000
VDD_VALUE	VDD value	3300 (mV)
USE_RTOS	Enables the use of RTOS	FALSE (for future use)
PREFETCH_ENABLE	Enables prefetch feature	FALSE
INSTRUCTION_CACHE_ENABLE	Enables I-cache feature	TRUE
DATA_CACHE_ENABLE	Enables D-cache feature	TRUE

The stm32l4xx_hal_conf_template.h file is located in the HAL drivers *Inc* folder. It should be copied to the user folder, renamed and modified as described above.

By default, the values defined in the stm32l4xx_hal_conf_template.h file are the same as the ones used for the examples and demonstrations. All HAL include files are enabled so that they can be used in the user code without modifications.

2.11 HAL system peripheral handling

This chapter gives an overview of how the system peripherals are handled by the HAL drivers. The full API list is provided within each peripheral driver description section.

2.11.1 Clock

Two main functions can be used to configure the system clock:

- HAL_RCC_OscConfig (RCC_OscInitTypeDef *RCC_OscInitStruct). This function configures/enables multiple clock sources (HSE, HSI, MSI, LSE, LSI, PLL).
- HAL_RCC_ClockConfig (RCC_ClkInitTypeDef *RCC_ClkInitStruct, uint32_t FLatency). This function
  - selects the system clock source
  - configures AHB, APB1 and APB2 clock dividers
  - configures the number of Flash memory wait states
  - updates the SysTick configuration when HCLK clock changes.

Some peripheral clocks are not derived from the system clock (RTC, USB…). In this case, the clock configuration is performed by an extended API defined in stm32l4xx_hal_rcc_ex.c: *HAL_RCCEx_PeriphCLKConfig(RCC_PeriphCLKInitTypeDef *PeriphClkInit)*.

Additional RCC HAL driver functions are available:

- HAL_RCC_DeInit() Clock de-initialization function that returns clock configuration to reset state
- Get clock functions that allow retreiving various clock configurations (system clock, HCLK, PCLK1, PCLK2, …)
- MCO and CSS configuration functions

A set of macros are defined in stm32l4xx_hal_rcc.h and stm32l4xx_hal_rcc_ex.h. They allow executing elementary operations on RCC block registers, such as peripherals clock gating/reset control:

- __HAL_PPP_CLK_ENABLE/__HAL_PPP_CLK_DISABLE to enable/disable the peripheral clock
- __HAL_PPP_FORCE_RESET/__HAL_PPP_RELEASE_RESET to force/release peripheral reset
- __HAL_PPP_CLK_SLEEP_ENABLE/__HAL_PPP_CLK_SLEEP_DISABLE to enable/disable the peripheral clock during low power (Sleep) mode.
- __HAL_PPP_IS_CLK_ENABLED/__HAL_PPP_IS_CLK_DISABLED to query about the enabled/disabled status of the peripheral clock.
- __HAL_PPP_IS_CLK_SLEEP_ENABLED/__HAL_PPP_IS_CLK_SLEEP_DISABLED to query about the enabled/disabled status of the peripheral clock during low power (Sleep) mode.

2.11.2 GPIOs

GPIO HAL APIs are the following:

- HAL_GPIO_Init() / HAL_GPIO_DeInit()
- HAL_GPIO_ReadPin() / HAL_GPIO_WritePin()
- HAL_GPIO_TogglePin ().

In addition to standard GPIO modes (input, output, analog), the pin mode can be configured as EXTI with interrupt or event generation.

When selecting EXTI mode with interrupt generation, the user must call HAL_GPIO_EXTI_IRQHandler() from stm32l4xx_it.c and implement HAL_GPIO_EXTI_Callback()

The table below describes the GPIO_InitTypeDef structure field.

Table 13: Description of GPIO_InitTypeDef structure

Structure field	Description
Pin	Specifies the GPIO pins to be configured. Possible values: GPIO_PIN_x or GPIO_PIN_All, where x[0..15]
Mode	Specifies the operating mode for the selected pins: GPIO mode or EXTI mode. Possible values are: • GPIO mode – GPIO_MODE_INPUT: Input floating – GPIO_MODE_OUTPUT_PP: Output push-pull – GPIO_MODE_OUTPUT_OD: Output open drain – GPIO_MODE_AF_PP: Alternate Function push-pull – GPIO_MODE_AF_OD: Alternate Function open drain – GPIO_MODE_ANALOG: Analog mode – GPIO_MODE_ANALOG_ADC_CONTROL: ADC analog mode • External Interrupt mode – GPIO_MODE_IT_RISING: Rising edge trigger detection – GPIO_MODE_IT_FALLING: Falling edge trigger detection – GPIO_MODE_IT_RISING_FALLING: Rising/Falling edge trigger detection • External Event mode – GPIO_MODE_EVT_RISING: Rising edge trigger detection – GPIO_MODE_EVT_FALLING: Falling edge trigger detection – GPIO_MODE_EVT_RISING_FALLING: Rising/Falling edge trigger detection
Pull	Specifies the Pull-up or Pull-down activation for the selected pins. Possible values are: GPIO_NOPULL GPIO_PULLUP GPIO_PULLDOWN
Speed	Specifies the speed for the selected pins Possible values are: GPIO_SPEED_FREQ_LOW GPIO_SPEED_FREQ_MEDIUM GPIO_SPEED_FREQ_HIGH GPIO_SPEED_FREQ_VERY_HIGH

Please find below typical GPIO configuration examples:

- Configuring GPIOs as output push-pull to drive external LEDs:

```
GPIO InitStruct.Pin = GPIO PIN 12 | GPIO PIN 13 | GPIO PIN 14 | GPIO PIN 15;
GPIO InitStruct.Mode = GPIO MODE OUTPUT PP;
GPIO InitStruct.Pull = GPIO PULLUP;
GPIO_InitStruct.Speed = GPIO_SPEED_FREQ_MEDIUM;
HAL_GPIO_Init(GPIOD, &GPIO_InitStruct);
```

- Configuring PA0 as external interrupt with falling edge sensitivity:

```
GPIO InitStructure.Mode = GPIO MODE IT FALLING;
GPIO_InitStructure.Pull = GPIO_NOPULL;
GPIO_InitStructure.Pin = GPIO_PIN_0;
HAL_GPIO_Init(GPIOA, &GPIO_InitStructure);
```

2.11.3 Cortex NVIC and SysTick timer

The Cortex HAL driver, stm32l4xx_hal_cortex.c, provides APIs to handle NVIC and Systick. The supported APIs include:

- HAL_NVIC_SetPriority()/ HAL_NVIC_SetPriorityGrouping()
- HAL_NVIC_GetPriority() / HAL_NVIC_GetPriorityGrouping()
- HAL_NVIC_EnableIRQ()/HAL_NVIC_DisableIRQ()
- HAL_NVIC_SystemReset()
- HAL_SYSTICK_IRQHandler()
- HAL_NVIC_GetPendingIRQ() / HAL_NVIC_SetPendingIRQ () / HAL_NVIC_ClearPendingIRQ()
- HAL_NVIC_GetActive(IRQn)
- HAL_SYSTICK_Config()
- HAL_SYSTICK_CLKSourceConfig()
- HAL_SYSTICK_Callback()

2.11.4 PWR

The PWR HAL driver handles power management. The features shared between all STM32 Series are listed below:

- PVD configuration, enabling/disabling and interrupt handling
  - HAL_PWR_ConfigPVD()
  - HAL_PWR_EnablePVD() / HAL_PWR_DisablePVD()
  - HAL_PWR_PVD_IRQHandler()
  - HAL_PWR_PVDCallback()
- Wakeup pin configuration
  - HAL_PWR_EnableWakeUpPin() / HAL_PWR_DisableWakeUpPin()
- Low-power mode entry
  - HAL_PWR_EnterSLEEPMode()
  - HAL_PWR_EnterSTOPMode() (kept for compatibility with other family but identical to HAL_PWREx_EnterSTOP0Mode() or HAL_PWREx_EnterSTOP1Mode() (see hereafter))
  - HAL_PWR_EnterSTANDBYMode()
- STM32L4 series and STM32L4+ series new low-power management features:
  - HAL_PWREx_EnterSTOP0Mode()
  - HAL_PWREx_EnterSTOP1Mode()
  - HAL_PWREx_EnterSTOP2Mode()
  - HAL_PWREx_EnterSHUTDOWNMode()

2.11.5 EXTI

The EXTI is not considered as a standalone peripheral but rather as a service used by other peripheral. As a result there are no EXTI APIs but each peripheral HAL driver implements the associated EXTI configuration and EXTI function are implemented as macros in its header file.

The first 16 EXTI lines connected to the GPIOs are managed within the GPIO driver. The GPIO_InitTypeDef structure allows configuring an I/O as external interrupt or external event.

The EXTI lines connected internally to the PVD, RTC, USB, and Ethernet are configured within the HAL drivers of these peripheral through the macros given in the table below. The EXTI internal connections depend on the targeted STM32 microcontroller (refer to the product datasheet for more details):

Table 14: Description of EXTI configuration macros

Macros	Description
__HAL_PPP_{SUBLOCK}__EXTI_ENABLE_IT()	Enables a given EXTI line interrupt Example: __HAL_PWR_PVD_EXTI_ENABLE_IT()
__HAL_PPP_{SUBLOCK}__EXTI_DISABLE_IT()	Disables a given EXTI line. Example: __HAL_PWR_PVD_EXTI_DISABLE_IT()
__HAL_ PPP_{SUBLOCK}__EXTI_GET_FLAG()	Gets a given EXTI line interrupt flag pending bit status. Example: __HAL_PWR_PVD_EXTI_GET_FLAG()
__HAL_ PPP_{SUBLOCK}_EXTI_CLEAR_FLAG()	Clears a given EXTI line interrupt flag pending bit. Example; __HAL_PWR_PVD_EXTI_CLEAR_FLAG()
__HAL_ PPP_{SUBLOCK}_EXTI_GENERATE_SWIT()	Generates a software interrupt for a given EXTI line. Example: __HAL_PWR_PVD_EXTI_ GENERATE_SWIT ()
__HAL_PPP_SUBBLOCK_EXTI_ENABLE_EVENT()	Enable a given EXTI line event Example: __HAL_RTC_WAKEUP_EXTI_ENABLE_EVENT()
__HAL_PPP_SUBBLOCK_EXTI_DISABLE_EVENT()	Disable a given EXTI line event Example: __HAL_RTC_WAKEUP_EXTI_DISABLE_EVENT()
__HAL_ PPP_SUBBLOCK_EXTI_ENABLE_RISING_EDGE()	Configure an EXTI Interrupt or Event on rising edge
__HAL_ PPP_SUBBLOCK_EXTI_DISABLE_FALLING_EDGE()	Enable an EXTI Interrupt or Event on Falling edge
__HAL_ PPP_SUBBLOCK_EXTI_DISABLE_RISING_EDGE()	Disable an EXTI Interrupt or Event on rising edge
__HAL_ PPP_SUBBLOCK_EXTI_DISABLE_FALLING_EDGE()	Disable an EXTI Interrupt or Event on Falling edge
__HAL_ PPP_SUBBLOCK_EXTI_ENABLE_RISING_FALLING_ EDGE()	Enable an EXTI Interrupt or Event on Rising/Falling edge
__HAL_ PPP_SUBBLOCK_EXTI_DISABLE_RISING_FALLING _EDGE()	Disable an EXTI Interrupt or Event on Rising/Falling edge

If the EXTI interrupt mode is selected, the user application must call HAL_PPP_FUNCTION_IRQHandler() (for example HAL_PWR_PVD_IRQHandler()), from stm32l4xx_it.c file, and implement HAL_PPP_FUNCTIONCallback() callback function (for example HAL_PWR_PVDCallback().

2.11.6 DMA

The DMA HAL driver allows enabling and configuring the peripheral to be connected to the DMA Channels (except for internal SRAM/FLASH memory which do not require any initialization). Refer to the product reference manual for details on the DMA request corresponding to each peripheral.

For a given channel, HAL_DMA_Init() API allows programming the required configuration through the following parameters:

- Transfer Direction
- Source and Destination data formats
- Normal or Circular mode
- Channel Priority level
- Source and Destination Increment mode
- Hardware request connected to the peripheral

Two operating modes are available:

- Polling mode I/O operation
  a. Use HAL_DMA_Start() to start DMA transfer when the source and destination addresses and the Length of data to be transferred have been configured.
  b. Use HAL_DMA_PollForTransfer() to poll for the end of current transfer. In this case a fixed timeout can be configured depending on the user application.
- Interrupt mode I/O operation
  a. Configure the DMA interrupt priority using HAL_NVIC_SetPriority()
  b. Enable the DMA IRQ handler using HAL_NVIC_EnableIRQ()
  c. Use HAL_DMA_Start_IT() to start DMA transfer when the source and destination addresses and the length of data to be transferred have been confgured. In this case the DMA interrupt is configured.
  d. Use HAL_DMA_IRQHandler() called under DMA_IRQHandler() Interrupt subroutine
  e. When data transfer is complete, HAL_DMA_IRQHandler() function is executed and a user function can be called by customizing XferCpltCallback and XferErrorCallback function pointer (i.e. a member of DMA handle structure).

Additional functions and macros are available to ensure efficient DMA management:

- Use HAL_DMA_GetState() function to return the DMA state and HAL_DMA_GetError() in case of error detection.
- Use HAL_DMA_Abort() function to abort the current transfer

The most used DMA HAL driver macros are the following:

- __HAL_DMA_ENABLE: enables the specified DMA channel.
- __HAL_DMA_DISABLE: disables the specified DMA channel.
- __HAL_DMA_GET_FLAG: gets the DMA channel pending flags.
- __HAL_DMA_CLEAR_FLAG: clears the DMA channel pending flags.
- __HAL_DMA_ENABLE_IT: enables the specified DMA channel interrupts.
- __HAL_DMA_DISABLE_IT: disables the specified DMA channel interrupts.
- __HAL_DMA_GET_IT_SOURCE: checks whether the specified DMA channel interrupt has been enabled or not.

When a peripheral is used in DMA mode, the DMA initialization should be done in the HAL_PPP_MspInit() callback. In addition, the user application should associate the DMA handle to the PPP handle (refer to section “HAL IO operation

functions”).

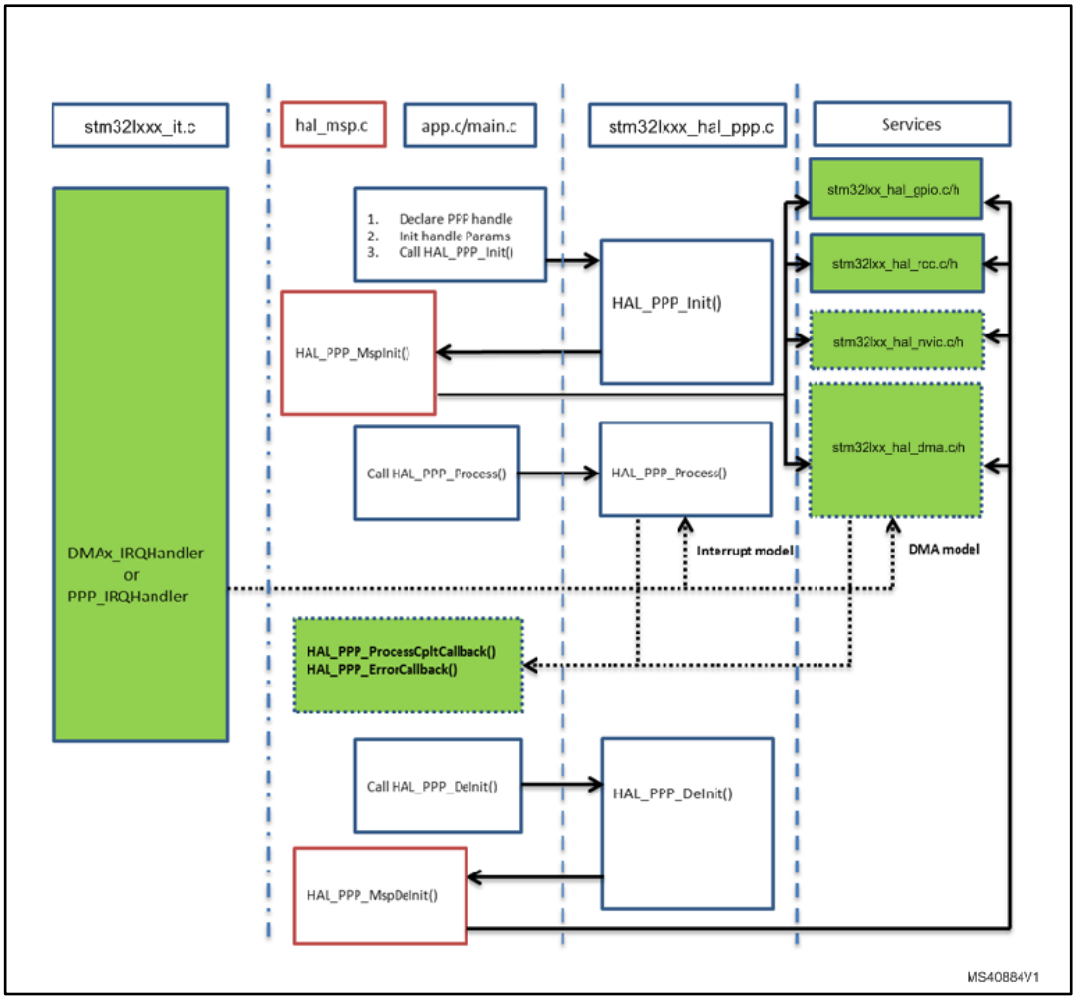
DMA channel callbacks need to be initialized by the user application only in case of memory-to-memory transfer. However when peripheral-to-memory transfers are used, these callbacks are automatically initialized by calling a process API function that uses the DMA.

2.12 How to use HAL drivers

2.12.1 HAL usage models

The following figure shows the typical use of the HAL driver and the interaction between the application user, the HAL driver and the interrupts.

Figure 7: HAL driver model



The functions implemented in the HAL driver are shown in green, the functions called from interrupt handlers in dotted lines, and the msp functions implemented in the user application in red. Non-dotted lines represent the interactions between the user application functions.

Basically, the HAL driver APIs are called from user files and optionally from interrupt handlers file when the APIs based on the DMA or the PPP peripheral dedicated interrupts are used.

When DMA or PPP peripheral interrupts are used, the PPP process complete callbacks are called to inform the user about the process completion in real-time event mode (interrupts). Note that the same process completion callbacks are used for DMA in interrupt mode.

2.12.2 HAL initialization

2.12.2.1 HAL global initialization

In addition to the peripheral initialization and de-initialization functions, a set of APIs are provided to initialize the HAL core implemented in file stm32l4xx_hal.c.

- HAL_Init(): this function must be called at application startup to
  - initialize data/instruction cache and pre-fetch queue
  - set SysTick timer to generate an interrupt each 1ms (based on HSI clock) with the lowest priority
  - call HAL_MspInit() user callback function to perform system level initializations (Clock, GPIOs, DMA, interrupts). HAL_MspInit() is defined as “weak” empty function in the HAL drivers.
- HAL_DeInit()
  - resets all peripherals
  - calls function HAL_MspDeInit() which a is user callback function to do system level De-Initalizations.
- HAL_GetTick(): this function gets current SysTick counter value (incremented in SysTick interrupt) used by peripherals drivers to handle timeouts.
- HAL_Delay(). this function implements a delay (expressed in milliseconds) using the SysTick timer.
  Care must be taken when using HAL_Delay() since this function provides an accurate delay (expressed in milliseconds) based on a variable incremented in SysTick ISR. This means that if HAL_Delay() is called from a peripheral ISR, then the SysTick interrupt must have highest priority (numerically lower) than the peripheral interrupt, otherwise the caller ISR will be blocked.

2.12.2.2 System clock initialization

The clock configuration is done at the beginning of the user code. However the user can change the configuration of the clock in his own code. Please find below the typical Clock configuration sequence to reach the maximum 80 MHz clock frequency based on the HSE clock:

```
 void SystemClock_Config(void)
{
   RCC ClkInitTypeDef clkinitstruct = {0};
   RCC_OscInitTypeDef oscinitstruct = {0};
/* Configure PLLs------------------------------------------------------*/
/* PLL configuration: PLLCLK =  (HSE/PLLM * PLLN) / PLLR = (16/1 * 20) / 2 = 80
MHz*/
/* Enable HSE Oscillator and activate PLL with HSE as source */
   oscinitstruct.OscillatorType =  RCC OSCILLATORTYPE HSE;
   oscinitstruct.HSEState =   RCC_HSE_ON;
   oscinitstruct.PLL.PLLState = RCC_PLL_ON;
   oscinitstruct.PLL.PLLSource =   RCC PLLSOURCE HSE;
   oscinitstruct.PLL.PLLM = 1;
   oscinitstruct.PLL.PLLN = 20;
   oscinitstruct.PLL.PLLR = 2;
   oscinitstruct.PLL.PLLL = 7;
   oscinitstruct.PLL.PLLQ = 4;
   if   (HAL_RCC_OscConfig(&oscinitstruct)!= HAL_OK)
```

```
   {
    /* Initialization Error */
       while(1);
   }
   /* Select PLL as system clock source and configure the HCLK, PCLK1 and PCLK2
clocks dividers    */
   clkinitstruct.ClockType = (RCC_CLOCKTYPE_SYSCLK I   RCC_CLOCKTYPE_HCLK I
RCC_CLOCKTYPE_PCLK1 I RCC_CLOCKTYPE_PCLK2);
   clkinitstruct.SYSCLKSource = RCC_SYSCLKSOURCE_PLLCLK;
   clkinitstruct.AHBCLKDivider = RCC SYSCLK DIV1;
   clkinitstruct.APB2CLKDivider =   RCC HCLK DIV1;
   clkinitstruct.APB1CLKDivider = RCC_HCLK_DIV1;
   if
      (HAL_RCC_ClockConfig(&clkinitstruct,FLASH_LATENCY_4)!= HAL_OK)
    {
      /*   Initialization Error */
     while(1);
    }
 }
```

2.12.2.3 HAL MSP initialization process

The peripheral initialization is done through *HAL_PPP_Init()* while the hardware resources initialization used by a peripheral (PPP) is performed during this initialization by calling MSP callback function *HAL_PPP_MspInit().*

The MspInit callback performs the low level initialization related to the different additional hardware resources: RCC, GPIO, NVIC and DMA.

All the HAL drivers with handles include two MSP callbacks for initialization and de-initialization:

```
/**
* @brief Initializes the PPP MSP.
* @param hppp: PPP handle
* @retval None */
void __weak HAL_PPP_MspInit(PPP_HandleTypeDef *hppp) {
/* NOTE: This function Should not be modified, when the callback is needed,
the HAL PPP MspInit could be implemented in the user file */
}
/**
* @brief DeInitializes PPP MSP.
* @param hppp: PPP handle
* @retval None */
void   weak HAL PPP MspDeInit(PPP HandleTypeDef *hppp) {
/* NOTE: This function Should not be modified, when the callback is needed,
the HAL_PPP_MspDeInit could be implemented in the user file */
}
```

The MSP callbacks are declared empty as weak functions in each peripheral driver. The user can use them to set the low level initialization code or omit them and use his own initialization routine.

The HAL MSP callback is implemented inside the *stm32l4xx_hal_msp.c* file in the user folders. An *stm32l4xx_hal_msp.c* file template is located in the HAL folder and should be copied to the user folder. It can be generated automatically by STM32CubeMX tool and further modified. Note that all the routines are declared as weak functions and could be overwritten or removed to use user low level initialization code.

stm32l4xx_hal_msp.c file contains the following functions:

Table 15: MSP functions

Routine	Description
void HAL_MspInit()	Global MSP initialization routine
void HAL_MspDeInit()	Global MSP de-initialization routine

Routine	Description
void HAL_PPP_MspInit()	PPP MSP initialization routine
void HAL_PPP_MspDeInit()	PPP MSP de-initialization routine

By default, if no peripheral needs to be de-initialized during the program execution, the whole MSP initialization is done in *Hal_MspInit()* and MSP De-Initialization in the *Hal_MspDeInit().* In this case the *HAL_PPP_MspInit()* and *HAL_PPP_MspDeInit()* are not implemented.

When one or more peripherals needs to be de-initialized in run time and the low level resources of a given peripheral need to be released and used by another peripheral, HAL_PPP_MspDeInit() and *HAL_PPP_MspInit()* are implemented for the concerned peripheral and other peripherals initialization and de-Initialization are kept in the global *HAL_MspInit()* and the *HAL_MspDeInit().*

If there is nothing to be initialized by the global *HAL_MspInit()* and *HAL_MspDeInit()*, the two routines can simply be omitted.

2.12.3 HAL IO operation process

The HAL functions with internal data processing like transmit, receive, write and read are generally provided with three data processing modes as follows:

- Polling mode
- Interrupt mode
- DMA mode

2.12.3.1 Polling mode

In Polling mode, the HAL functions return the process status when the data processing in blocking mode is complete. The operation is considered complete when the function returns the HAL_OK status, otherwise an error status is returned. The user can get more information through the *HAL_PPP_GetState()* function. The data processing is handled internally in a loop. A timeout (expressed in ms) is used to prevent process hanging.

The example below shows the typical Polling mode processing sequence:

```
HAL_StatusTypeDef HAL_PPP_Transmit ( PPP_HandleTypeDef * phandle, uint8_t pData,
int16_tSize,uint32_tTimeout)
{
if((pData == NULL ) || (Size == 0))
{
return HAL_ERROR;
}
(…) while (data processing is running)
{
if( timeout reached )
{
return HAL_TIMEOUT;
}
}
(…)
return HELIAC; }
```

2.12.3.2 Interrupt mode

In interrupt mode, the HAL function returns the process status after starting the data processing and enabling the appropriate interruption. The end of the operation is indicated by a callback declared as a weak function. It can be customized by the user to be informed in real-time about the process completion. The user can also get the process status through the *HAL_PPP_GetState()* function.

In interrupt mode, four functions are declared in the driver:

- *HAL_PPP_Process_IT()*: launch the process
- *HAL_PPP_IRQHandler()*: the global PPP peripheral interruption
- *__weak HAL_PPP_ProcessCpltCallback ()*: the callback relative to the process completion.
- *__weak HAL_PPP_ProcessErrorCallback()*: the callback relative to the process Error.

To use a process in interrupt mode, *HAL_PPP_Process_IT()* is called in the user file and HAL_PPP_IRQHandler in *stm32l4xx_it.c.*

The *HAL_PPP_ProcessCpltCallback()* function is declared as weak function in the driver. This means that the user can declare it again in the application. The function in the driver is not modified.

An example of use is illustrated below:

main.c file:

```
UART_HandleTypeDef UartHandle;
int main(void)
{
/* Set User Parameters */
UartHandle.Init.BaudRate = 9600;
UartHandle.Init.WordLength = UART_DATABITS_8;
UartHandle.Init.StopBits = UART_STOPBITS_1;
UartHandle.Init.Parity = UART_PARITY_NONE;
UartHandle.Init.HwFlowCtl = UART HWCONTROL NONE;
UartHandle.Init.Mode = UART_MODE_TX_RX;
UartHandle.Init.Instance = USART1;
HAL_UART_Init(&UartHandle);
HAL_UART_SendIT(&UartHandle, TxBuffer, sizeof(TxBuffer));
while (1);
}
void HAL_UART_TxCpltCallback(UART_HandleTypeDef *huart)
{
}
void HAL_UART_ErrorCallback(UART_HandleTypeDef *huart)
{
}
```

*stm32l4xx_it.c*file:

```
extern UART_HandleTypeDef UartHandle;
void USART1_IRQHandler(void)
{
HAL UART IRQHandler(&UartHandle);
}
```

2.12.3.3 DMA mode

In DMA mode, the HAL function returns the process status after starting the data processing through the DMA and after enabling the appropriate DMA interruption. The end of the operation is indicated by a callback declared as a weak function and can be customized by the user to be informed in real-time about the process completion. The user can also get the process status through the *HAL_PPP_GetState()* function. For the DMA mode, three functions are declared in the driver:

- *HAL_PPP_Process_DMA()*: launch the process
- *HAL_PPP_DMA_IRQHandler()*: the DMA interruption used by the PPP peripheral
- *__weak HAL_PPP_ProcessCpltCallback()*: the callback relative to the process completion.
- *__weak HAL_PPP_ErrorCpltCallback()*: the callback relative to the process Error.

To use a process in DMA mode, *HAL_PPP_Process_DMA()* is called in the user file and the *HAL_PPP_DMA_IRQHandler()* is placed in the *stm32l4xx_it.c*. When DMA mode is used, the DMA initialization is done in the *HAL_PPP_MspInit()* callback. The user should also associate the DMA handle to the PPP handle. For this purpose, the handles of all the peripheral drivers that use the DMA must be declared as follows:

```
typedef struct
{
PPP_TypeDef *Instance; /* Register base address */
PPP_InitTypeDef Init; /* PPP communication parameters */
HAL_StateTypeDef State; /* PPP communication state */
(…)
DMA_HandleTypeDef *hdma; /* associated DMA handle */
} PPP_HandleTypeDef;
```

The initialization is done as follows (UART example):

```
int main(void)
{
/* Set User Parameters */
UartHandle.Init.BaudRate = 9600;
UartHandle.Init.WordLength = UART_DATABITS_8;
UartHandle.Init.StopBits = UART_STOPBITS_1;
UartHandle.Init.Parity = UART_PARITY_NONE;
UartHandle.Init.HwFlowCtl = UART_HWCONTROL_NONE;
UartHandle.Init.Mode = UART_MODE_TX_RX;
UartHandle.Init.Instance = UART1;
HAL_UART_Init(&UartHandle);
(..)
}
void HAL_USART_MspInit (UART_HandleTypeDef * huart)
{
static DMA_HandleTypeDef hdma_tx;
static DMA_HandleTypeDef hdma_rx;
(…)
__HAL_LINKDMA(UartHandle, DMA_Handle_tx, hdma_tx);
__HAL_LINKDMA(UartHandle, DMA_Handle_rx, hdma_rx);
(…)
}
```

The *HAL_PPP_ProcessCpltCallback()* function is declared as weak function in the driver that means, the user can declare it again in the application code. The function in the driver should not be modified.

An example of use is illustrated below:

main.c file:

```
UART_HandleTypeDef UartHandle;
int main(void)
{
/* Set User Paramaters */
UartHandle.Init.BaudRate = 9600;
UartHandle.Init.WordLength = UART_DATABITS_8;
UartHandle.Init.StopBits = UART STOPBITS 1;
UartHandle.Init.Parity = UART PARITY NONE;
UartHandle.Init.HwFlowCtl = UART HWCONTROL NONE;
UartHandle.Init.Mode = UART_MODE_TX_RX; UartHandle.Init.Instance = USART1;
HAL_UART_Init(&UartHandle);
HAL_UART_Send_DMA(&UartHandle, TxBuffer, sizeof(TxBuffer));
while (1);
}
void HAL UART TxCpltCallback(UART HandleTypeDef *phuart)
{
}
void HAL_UART_TxErrorCallback(UART_HandleTypeDef *phuart)
{
}
```

stm32l4xx_it.c file:

```
extern UART HandleTypeDef UartHandle;
void DMAx IRQHandler(void)
{
HAL_DMA_IRQHandler(&UartHandle.DMA_Handle_tx);
}
```

HAL_USART_TxCpltCallback() and *HAL_USART_ErrorCallback()* should be linked in the *HAL_PPP_Process_DMA()* function to the DMA transfer complete callback and the DMA transfer Error callback by using the following statement:

```
HAL PPP Process DMA (PPP HandleTypeDef *hppp, Params….)
{
(…)
hppp->DMA_Handle->XferCpltCallback = HAL_UART_TxCpltCallback ;
hppp->DMA_Handle->XferErrorCallback = HAL_UART_ErrorCallback ;
(…)
}
```

2.12.4 Timeout and error management

2.12.4.1 Timeout management

The timeout is often used for the APIs that operate in polling mode. It defines the delay during which a blocking process should wait till an error is returned. An example is provided below:

```
HAL StatusTypeDef HAL DMA PollForTransfer(DMA HandleTypeDef *hdma, uint32 t
CompleteLevel, uint32_t Timeout)
```

The timeout possible value are the following:

Table 16: Timeout values

Timeout value	Description
0	No poll: Immediate process check and exit
1 ... (HAL_MAX_DELAY -1)(1)	Timeout in ms
HAL_MAX_DELAY	Infinite poll till process is successful

Notes:

(1)HAL_MAX_DELAY is defined in the stm32l4xx_hal_def.h as 0xFFFFFFFF

However, in some cases, a fixed timeout is used for system peripherals or internal HAL driver processes. In these cases, the timeout has the same meaning and is used in the same way, except when it is defined locally in the drivers and cannot be modified or introduced as an argument in the user application.

Example of fixed timeout:

```
#define LOCAL PROCESS TIMEOUT 100
HAL_StatusTypeDef HAL_PPP_Process(PPP_HandleTypeDef)
{
(…)
timeout = HAL GetTick() + LOCAL PROCESS TIMEOUT;
(…)
while(ProcessOngoing)
{
(…)
if(HAL GetTick() >= timeout)
{
/* Process unlocked */
__HAL_UNLOCK(hppp);
hppp->State= HAL_PPP_STATE_TIMEOUT;
return HAL PPP STATE TIMEOUT;
}
}
(…)
}
```

The following example shows how to use the timeout inside the polling functions:

```
HAL_PPP_StateTypeDef HAL_PPP_Poll (PPP_HandleTypeDef *hppp, uint32_t Timeout)
{
(…)
timeout = HAL GetTick() + Timeout;
(…)
while(ProcessOngoing)
{
(…)
if(Timeout != HAL_MAX_DELAY)
{
if(HAL_GetTick() >= timeout)
```

```
{
/* Process unlocked */
__HAL_UNLOCK(hppp);
hppp->State= HAL_PPP_STATE_TIMEOUT;
return hppp->State;
}
}
(…)
}
```

2.12.4.2 Error management

The HAL drivers implement a check on the following items:

- Valid parameters: for some process the used parameters should be valid and already defined, otherwise the system may crash or go into an undefined state. These critical parameters are checked before being used (see example below).

```
HAL StatusTypeDef HAL PPP Process(PPP HandleTypeDef* hppp, uint32 t *pdata, uint32
Size)
{ if ((pData == NULL ) || (Size == 0))
{ return HAL_ERROR;
}
}
```

- Valid handle: the PPP peripheral handle is the most important argument since it keeps the PPP driver vital parameters. It is always checked in the beginning of the *HAL_PPP_Init()* function.

```
HAL StatusTypeDef HAL PPP Init(PPP HandleTypeDef* hppp)
{ if (hppp == NULL) //the handle should be already allocated
{ return HAL_ERROR;
}
}
```

- Timeout error: the following statement is used when a timeout error occurs:

```
while (Process ongoing)
{ timeout = HAL_GetTick() + Timeout;
while (data processing is running)
{ if(timeout)
{ return HAL_TIMEOUT;
}
}
```

When an error occurs during a peripheral process, *HAL_PPP_Process ()* returns with a *HAL_ERROR* status. The HAL PPP driver implements the *HAL_PPP_GetError ()* to allow retrieving the origin of the error.

```
HAL_PPP_ErrorTypeDef HAL_PPP_GetError (PPP_HandleTypeDef *hppp);
```

In all peripheral handles, a *HAL_PPP_ErrorTypeDef* is defined and used to store the last error code.

```
typedef struct
{
PPP TypeDef * Instance; /* PPP registers base address */
PPP InitTypeDef Init; /* PPP initialization parameters */
HAL LockTypeDef Lock; /* PPP locking object */
__IO HAL_PPP_StateTypeDef State; /* PPP state */
__IO HAL_PPP_ErrorTypeDef ErrorCode; /* PPP Error code */
(…)
/* PPP specific parameters */
}
PPP_HandleTypeDef;
```

The error state and the peripheral global state are always updated before returning an error:

```
PPP->State = HAL_PPP_READY;  /* Set the peripheral ready */
PP->ErrorCode = HAL ERRORCODE ; /* Set the error code */
 HAL UNLOCK(PPP) ; /* Unlock the PPP resources */
return HAL_ERROR;  /*return with HAL error */
```

HAL_PPP_GetError () must be used in interrupt mode in the error callback:

```
void HAL PPP ProcessCpltCallback(PPP HandleTypeDef *hspi)
{
ErrorCode = HAL_PPP_GetError (hppp); /* retreive error code */
}
```

2.12.4.3 Run-time checking

The HAL implements run-time failure detection by checking the input values of all HAL driver functions. The run-time checking is achieved by using an *assert_param* macro. This macro is used in all the HAL driver functions which have an input parameter. It allows verifying that the input value lies within the parameter allowed values.

To enable the run-time checking, use the *assert_param* macro, and leave the define ***USE_FULL_ASSERT*** uncommented in *stm32l4xx_hal_conf.h* file.

```
void HAL_UART_Init(UART_HandleTypeDef *huart)
{
(..) /* Check the parameters */
assert param(IS UART INSTANCE(huart->Instance));
assert param(IS UART BAUDRATE(huart->Init.BaudRate));
assert_param(IS_UART_WORD_LENGTH(huart->Init.WordLength));
assert_param(IS_UART_STOPBITS(huart->Init.StopBits));
assert_param(IS_UART_PARITY(huart->Init.Parity));
assert param(IS UART MODE(huart->Init.Mode));
assert param(IS UART HARDWARE FLOW CONTROL(huart->Init.HwFlowCtl));
(..)
```

```
/** @defgroup UART_Word_Length *
@{
*/
#define UART WORDLENGTH 8B ((uint32 t)0x00000000)
#define UART_WORDLENGTH_9B ((uint32_t)USART_CR1_M)
#define IS_UART_WORD_LENGTH(LENGTH) (((LENGTH) == UART_WORDLENGTH_8B) ||
\ ((LENGTH) == UART_WORDLENGTH_9B))
```

If the expression passed to the assert_param macro is false, the*assert_failed* function is called and returns the name of the source file and the source line number of the call that failed. If the expression is true, no value is returned.

The *assert_param* macro is implemented in stm32l4xx_hal_conf.h:

```
/* Exported macro ------------------------------------------------------------*/
#ifdef USE_FULL_ASSERT
/**
* @brief The assert param macro is used for function's parameters check.
* @param expr: If expr is false, it calls assert failed function
* which reports the name of the source file and the source
* line number of the call that failed.
* If expr is true, it returns no value.
* @retval None */
#define assert param(expr) ((expr)?(void)0:assert failed((uint8 t *)  FILE  ,
__LINE__))
/* Exported functions --------------------------------------*/
void assert failed(uint8 t* file, uint32 t line);
#else
#define assert param(expr)((void)0)
#endif /* USE_FULL_ASSERT */
```

The *assert_failed* function is implemented in the main.c file or in any other user C file:

```
#ifdef USE_FULL_ASSERT /**
* @brief Reports the name of the source file and the source line number
* where the assert param error has occurred.
* @param file: pointer to the source file name
* @param line: assert_param error line source number
* @retval None */
void assert failed(uint8 t* file, uint32 t line)
{
/* User can add his own implementation to report the file name and line number,
ex: printf("Wrong parameters value: file %s on line %d\r\n", file, line) */
/* Infinite loop */
while (1)
{
}
}
```

Because of the overhead run-time checking introduces, it is recommended to use it during application code development and debugging, and to remove it from the final application to improve code size and speed.

3 Overview of low-layer drivers

The low-layer (LL) drivers are designed to offer a fast light-weight expert-oriented layer which is closer to the hardware than the HAL. Contrary to the HAL, LL APIs are not provided for peripherals where optimized access is not a key feature, or those requiring heavy software configuration and/or complex upper-level stack (such as FSMC, USB or SDMMC).

The LL drivers feature:

- A set of functions to initialize peripheral main features according to the parameters specified in data structures
- A set of functions used to fill initialization data structures with the reset values of each field
- Functions to perform peripheral de-initialization (peripheral registers restored to their default values)
- A set of inline functions for direct and atomic register access
- Full independence from HAL since LL drivers can be used either in standalone mode (without HAL drivers) or in mixed mode (with HAL drivers)
- Full coverage of the supported peripheral features.

The low-layer drivers provide hardware services based on the available features of the STM32 peripherals. These services reflect exactly the hardware capabilities and provide one-shot operations that must be called following the programming model described in the microcontroller line reference manual. As a result, the LL services do not implement any processing and do not require any additional memory resources to save their states, counter or data pointers: all the operations are performed by changing the associated peripheral registers content.

3.1 Low-layer files

The low-layer drivers are built around header/C files (one per each supported peripheral) plus five header files for some System and Cortex related features.

Table 17: LL driver files

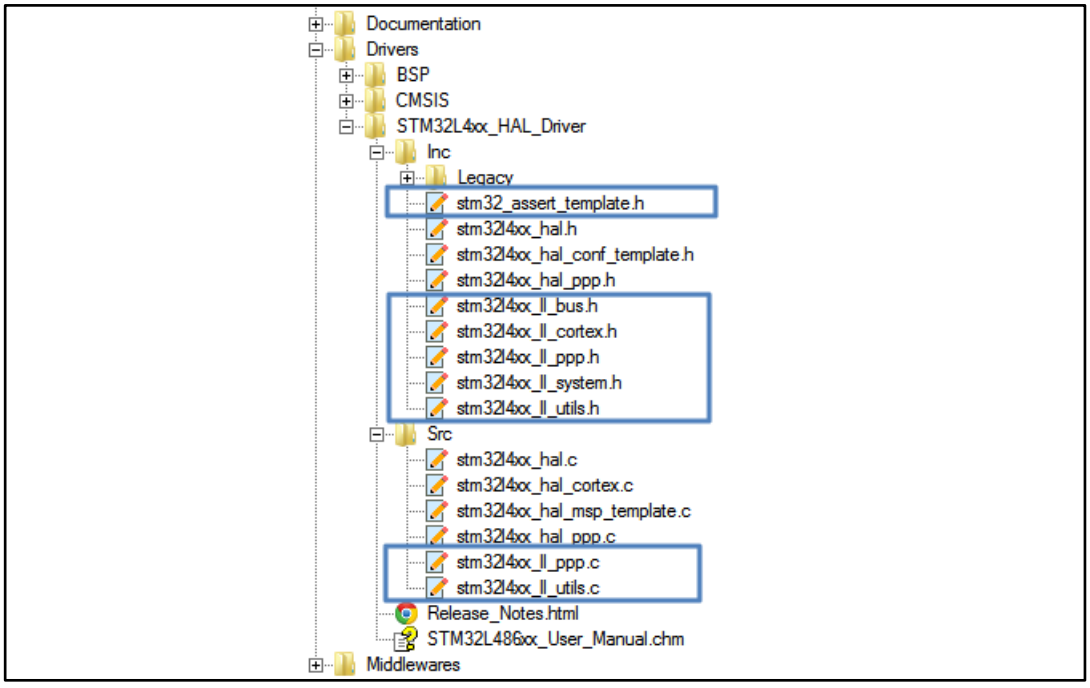
File	Description
stm32l4xx_ll_bus.h	This is the h-source file for core bus control and peripheral clock activation and deactivation *Example: LL_AHB2_GRP1_EnableClock*
stm32l4xx_ll_ppp.h/.c	stm32l4xx_ll_ppp.c provides peripheral initialization functions such as LL_PPP_Init(), LL_PPP_StructInit(), LL_PPP_DeInit(). All the other APIs are definined within stm32l4xx_ll_ppp.h file. The low-layer PPP driver is a standalone module. To use it, the application must include it in the xx_ll_ppp.h file.
stm32l4xx_ll_cortex.h	Cortex-M related register operation APIs including the Systick, Low power (LL_SYSTICK_xxxxx, LL_LPM_xxxxx "Low Power Mode" ...)
stm32l4xx_ll_utils.h/.c	This file covers the generic APIs: • Read of device unique ID and electronic signature • Timebase and delay management • System clock configuration.
*stm32l4*xx_ll_system.h	System related operations (LL_SYSCFG_xxx, LL_DBGMCU_xxx, LL_FLASH_xxx and LL_VREFBUF_xxx)

File	Description
stm32_assert_template.h	Template file allowing to define the assert_param macro, that is used when run-time checking is enabled. This file is required only when the LL drivers are used in standalone mode (without calling the HAL APIs). It should be copied to the application folder and renamed to stm32_assert.h.

There is no configuration file for the LL drivers.

The low-layer files are located in the same HAL driver folder.

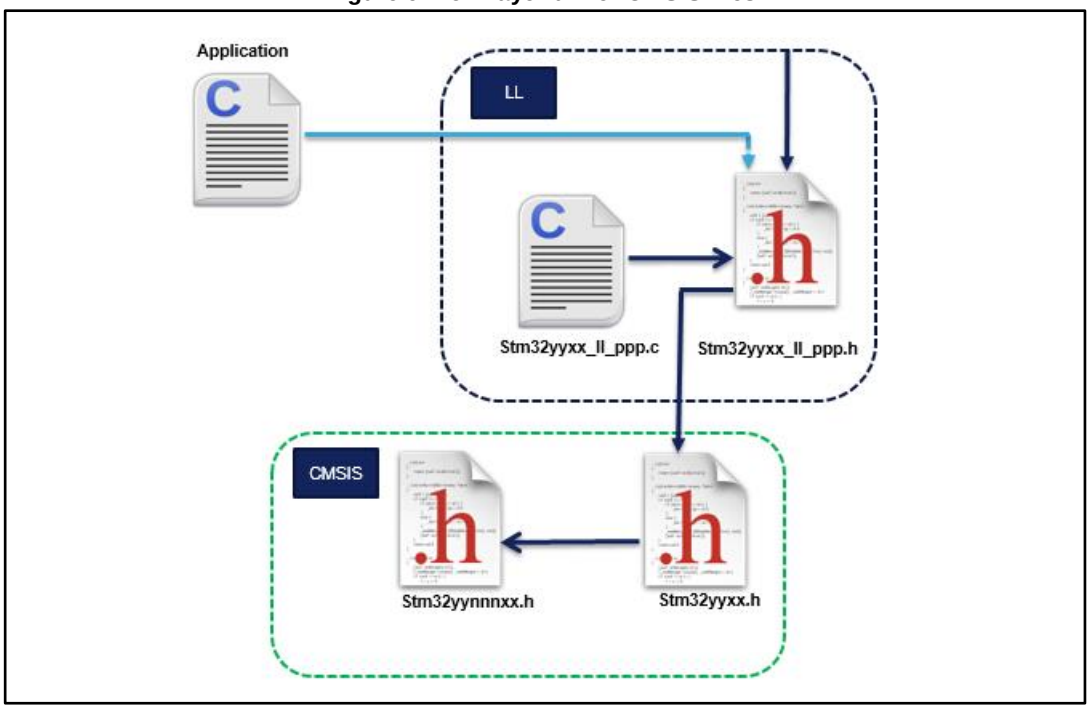
Figure 8: Low-layer driver folders



In general, low-layer drivers include only the STM32 CMSIS device file.

```
#include "stm32yyxx.h"
```

Figure 9: Low-layer driver CMSIS files



Application files have to include only the used low-layer driver header files.

3.2 Overview of low-layer APIs and naming rules

3.2.1 Peripheral initialization functions

The LL drivers offer three set of initialization functions. They are defined in stm32l4xx_ll_ppp.c file:

- Functions to initialize peripheral main features according to the parameters specified in data structures
- A set of functions used to fill initialization data structures with the reset values of each field
- Function for peripheral de-initialization (peripheral registers restored to their default values)

The definition of these LL initialization functions and associated resources (structure, literals and prototypes) is conditioned by a compilation switch: *USE_FULL_LL_DRIVER*. To use these functions, this switch must be added in the toolchain compiler preprocessor or to any generic header file which is processed before the LL drivers.

The below table shows the list of the common functions provided for all the supported peripherals:

Table 18: Common peripheral initialization functions

Functions	Return Type	Parameters	Description
LL_PPP_ Init	*ErrorStatus*	• *PPP_TypeDef* PPPx* • *LL_PPP_InitTypeDef* PPP_InitStruct*	Initializes the peripheral main features according to the parameters specified in PPP_InitStruct. Example: LL_USART_Init(USART_TypeDef *USARTx, LL_USART_InitTypeDef *USART_InitStruct)
LL_PPP_StructInit	*void*	• *LL_PPP_InitTypeDef* PPP_InitStruct*	Fills each PPP_InitStruct member with its default value. Example. LL_USART_StructInit(LL_USART_InitTypeDef *USART_InitStruct)
LL_PPP_DeInit	*ErrorStatus*	• *PPP_TypeDef* PPPx*	De-initializes the peripheral registers, that is restore them to their default reset values. Example. LL_USART_DeInit(USART_TypeDef *USARTx)

Additional functions are available for some peripherals (refer to *Table 19: "Optional peripheral initialization functions"*).

Table 19: Optional peripheral initialization functions

Functions	Return Type	Parameters	Examples
LL_PPP{_CATEGORY}_Init	*Error Status*	• *PPP_TypeDef* PPPx* • *LL_PPP{_CATEGORY}_InitTypeDef* PPP{_CATEGORY}_InitStruct*	Initializes peripheral features according to the parameters specified in PPP_InitStruct. Example: LL_ADC_INJ_Init(ADC_TypeDef *ADCx, LL_ADC_INJ_InitTypeDef *ADC_INJ_InitStruct) LL_RTC_TIME_Init(RTC_TypeDef *RTCx, uint32_t RTC_Format, LL_RTC_TimeTypeDef *RTC_TimeStruct) LL_RTC_DATE_Init(RTC_TypeDef *RTCx, uint32_t RTC_Format, LL_RTC_DateTypeDef *RTC_DateStruct) LL_TIM_IC_Init(TIM_TypeDef* TIMx, uint32_t Channel, LL_TIM_IC_InitTypeDef* TIM_IC_InitStruct) LL_TIM_ENCODER_Init(TIM_TypeDef* TIMx, LL_TIM_ENCODER_InitTypeDef* TIM_EncoderInitStruct)
LL_PPP{_CATEGORY}_StructInit	*void*	*LL_PPP{_CATEGORY}_InitTypeDef* PPP{_CATEGORY}_InitStruct*	Fills each *PPP{_CATEGORY}_InitStruct* member with its default value. Example: LL_ADC_INJ_StructInit(LL_ADC_INJ_InitTypeDef *ADC_INJ_InitStruct)
LL_PPP_CommonInit	*Error Status*	• *PPP_TypeDef* PPPx* • *LL_PPP_CommonInitTypeDef* PPP_CommonInitStruct*	Initializes the common features shared between different instances of the same peripheral. Example: LL_ADC_CommonInit(ADC_Common_TypeDef *ADCxy_COMMON, LL_ADC_CommonInitTypeDef *ADC_CommonInitStruct)

Functions	Return Type	Parameters	Examples
LL_PPP_Common StructInit	*void*	*LL_PPP_CommonInit TypeDef* PPP_CommonInitStruct*	Fills each PPP_CommonInitStruct member with its default value Example: LL_ADC_CommonStructInit(LL_ADC _CommonInitTypeDef *ADC_CommonInitStruct)
LL_PPP_ClockInit	*ErrorStat us*	• *PPP_TypeDef* PPPx* • *LL_PPP_ClockInit TypeDef* PPP_ClockInit Struct*	Initializes the peripheral clock configuration in synchronous mode. Example: LL_USART_ClockInit(USART_Type Def *USARTx, LL_USART_ClockInitTypeDef *USART_ClockInitStruct)
LL_PPP_ClockStruct Init	*void*	*LL_PPP_ClockInitType Def* PPP_ClockInitStruct*	Fills each *PPP_ClockInitStruct* member with its default value Example: LL_USART_ClockStructInit(LL_USA RT_ClockInitTypeDef *USART_ClockInitStruct)

3.2.1.1 Run-time checking

Like HAL drivers, LL initialization functions implement run-time failure detection by checking the input values of all LL driver functions. For more details please refer to *Section 2.12.4.3: "Run-time checking"*.

When using the LL drivers in standalone mode (without calling HAL functions), the following actions are required to use run-time checking:

1. Copy stm32_assert_template.h to the application folder and rename it to stm32_assert.h. This file defines the assert_param macro which is used when run-time checking is enabled.
2. Include stm32_assert.h file within the application main header file.
3. Add the USE_FULL_ASSERT compilation switch in the toolchain compiler preprocessor or in any generic header file which is processed before the stm32_assert.h driver.

Run-time checking is not available for LL inline functions.

3.2.2 Peripheral register-level configuration functions

On top of the peripheral initialization functions, the LL drivers offer a set of inline functions for direct atomic register access. Their format is as follows:

```
__STATIC_INLINE return_type LL_PPP_Function (PPPx_TypeDef *PPPx, args)
```

The “Function” naming is defined depending to the action category:

- **Specific Interrupt, DMA request and status flags management**: Set/Get/Clear/Enable/Disable flags on interrupt and status registers

Table 20: Specific Interrupt, DMA request and status flags management

Name	Examples
LL_PPP_{_CATEGORY}_ActionItem_BITNAME *LL_PPP{_CATEGORY}_IsItem_BITNAME_Action*	• LL_RCC_IsActiveFlag_LSIRDY • LL_RCC_IsActiveFlag_FWRST() • LL_ADC_ClearFlag_EOC(ADC1) • LL_DMA_ClearFlag_TCx(DMA_TypeDef* DMAx)

Table 21: Available function formats

Item	Action	Format
Flag	Get	*LL_PPP_IsActiveFlag_BITNAME*
	Clear	*LL_PPP_ClearFlag_BITNAME*
Interrupts	Enable	*LL_PPP_EnableIT_BITNAME*
	Disable	*LL_PPP_DisableIT_BITNAME*
	Get	*LL_PPP_IsEnabledIT_BITNAME*
DMA	Enable	*LL_PPP_EnableDMAReq_BITNAME*
	Disable	*LL_PPP_DisableDMAReq_BITNAME*
	Get	*LL_PPP_IsEnabledDMAReq_BITNAME*

BITNAME refers to the peripheral register bit name as described in the product line reference manual.

- **Peripheral clock activation/deactivation management**: Enable/Disable/Reset a peripheral clock

Table 22: Peripheral clock activation/deactivation management

Name	Examples
LL_BUS_GRPx_ActionClock{Mode}	• *LL_AHB2_GRP1_EnableClock (LL_AHB2_GRP1_PERIPH_GPIOA|LL_AHB2_GRP1_PERIPH_GPIOB)* • *by LL_APB1_GRP1_EnableClockSleep (LL_APB1_GRP1_PERIPH_DAC1)*

'x' corresponds to the group index and refers to the index of the modified register on a given bus.

- ***Peripheral activation/deactivation management***: Enable/disable a peripheral or activate/deactivate specific peripheral features

Table 23: Peripheral activation/deactivation management

Name	Examples
LL_PPP{_CATEGORY}_Action{Item} *LL_PPP{_CATEGORY}_IsItemAction*	• *LL_ADC_Enable ()* • *LL_ADC_StartCalibration();* • *LL_ADC_IsCalibrationOnGoing;* • *LL_RCC_HSI_Enable ()* • *LL_RCC_HSI_IsReady()*

- ***Peripheral configuration management***: Set/get a peripheral configuration settings

Table 24: Peripheral configuration management

Name	Examples
LL_PPP{_CATEGORY}_Set{ or Get}ConfigItem	*LL_USART_SetBaudRate (USART2, Clock, LL_USART_BAUDRATE_9600)*

- ***Peripheral register management***: Write/read the content of a register/retrun DMA relative register address

Table 25: Peripheral register management

Name
LL_PPP_WriteReg(__INSTANCE__, __REG__, __VALUE__)
LL_PPP_ReadReg(__INSTANCE__, __REG__)
*LL_PPP_DMA_GetRegAddr (PPP_TypeDef *PPPx,{Sub Instance if any ex: Channel} , {uint32_t Propriety})*

The Propriety is a variable used to identify the DMA transfer direction or the data register type.

4 Cohabiting of HAL and LL

The low-ayer APIs are designed to be used in standalone mode or combined with the HAL. They cannot be automatically used with the HAL for the same peripheral instance. If you use the LL APIs for a specific instance, you can still use the HAL APIs for other instances. Be careful that the low-layer APIs might overwrite some registers which content is mirrored in the HAL handles.

4.1 Low-layer driver used in standalone mode

The low-layer APIs can be used without calling the HAL driver services. This is done by simply including stm32l4xx_ll_ppp.h in the application files. The LL APIs for a given peripheral are called by executing the same sequence as the one recommended by the programming model in the corresponding product line reference manual. In this case the HAL drivers associated to the used peripheral can be removed from the workspace. However the STM32CubeL4 framework should be used in the same way as in the HAL drivers case which means that System file, startup file and CMSIS should always be used.

When the BSP drivers are included, the used HAL drivers associated with the BSP functions drivers should be included in the workspace, even if they are not used by the application layer.

4.2 Mixed use of low-layer APIs and HAL drivers

In this case the low-layer APIs are used in conjunction with the HAL drivers to achieve direct and register level based operations.

Mixed use is allowed, however some consideration should be taken into account:

- It is recommended to avoid using simultaneously the HAL APIs and the combination of low-layer APIs for a given peripheral instance. If this is the case, one or more private fields in the HAL PPP handle structure should be updated accordingly.
- For operations and processes that do not alter the handle fields including the initialization structure, the HAL driver APIs and the low-layer services can be used together for the same peripheral instance.
- The low-layer drivers can be used without any restriction with all the HAL drivers that are not based on handle objects (RCC, common HAL, flash and GPIO).

Several examples showing how to use HAL and LL in the same application are provided within stm32l4 firmware package (refer to Examples_MIX projects).

1. When the HAL Init/DeInit APIs are not used and are replaced by the low-layer macros, the InitMsp() functions are not called and the MSP initialization should be done in the user application.
2. When process APIs are not used and the corresponding function is performed through the low-layer APIs, the callbacks are not called and post processing or error management should be done by the user application.
3. When the LL APIs is used for process operations, the IRQ handler HAL APIs cannot be called and the IRQ should be implemented by the user application. Each LL driver implements the macros needed to read and clear the associated interrupt flags.

5 HAL System Driver

5.1 HAL Firmware driver API description

5.1.1 How to use this driver

The common HAL driver contains a set of generic and common APIs that can be used by the PPP peripheral drivers and the user to start using the HAL.

The HAL contains two APIs' categories:

- Common HAL APIs
- Services HAL APIs

5.1.2 Initialization and de-initialization functions

This section provides functions allowing to:

- Initialize the Flash interface the NVIC allocation and initial time base clock configuration.
- De-initialize common part of the HAL.
- Configure the time base source to have 1ms time base with a dedicated Tick interrupt priority.
  - SysTick timer is used by default as source of time base, but user can eventually implement his proper time base source (a general purpose timer for example or other time source), keeping in mind that Time base duration should be kept 1ms since PPP_TIMEOUT_VALUEs are defined and handled in milliseconds basis.
  - Time base configuration function (HAL_InitTick ()) is called automatically at the beginning of the program after reset by HAL_Init() or at any time when clock is configured, by HAL_RCC_ClockConfig().
  - Source of time base is configured to generate interrupts at regular time intervals. Care must be taken if HAL_Delay() is called from a peripheral ISR process, the Tick interrupt line must have higher priority (numerically lower) than the peripheral interrupt. Otherwise the caller ISR process will be blocked.
  - functions affecting time base configurations are declared as __weak to make override possible in case of other implementations in user file.

This section contains the following APIs:

- ***HAL_Init()***
- ***HAL_DeInit()***
- ***HAL_MspInit()***
- ***HAL_MspDeInit()***
- ***HAL_InitTick()***

5.1.3 HAL Control functions

This section provides functions allowing to:

- Provide a tick value in millisecond
- Provide a blocking delay in millisecond
- Suspend the time base source interrupt
- Resume the time base source interrupt
- Get the HAL API driver version
- Get the device identifier
- Get the device revision identifier