UM1734
User manual

STM32Cube™ USB device library

Introduction

The STM32Cube™ is an STMicroelectronics original initiative to make developers' lives easier by reducing development effort, time and cost. STM32Cube™ covers the whole STM32 portfolio.

STM32Cube™ includes:

- STM32CubeMX, a graphical software configuration tool that allows the generation of C initialization code using graphical wizards.
- A comprehensive embedded software platform, delivered per Series (such as STM32CubeF4 for STM32F4 Series)
  - The STM32Cube™ HAL, STM32 abstraction layer embedded software ensuring maximized portability across the STM32 portfolio,
  - A consistent set of middleware components such as RTOS, USB, TCP/IP, Graphics,
  - All embedded software utilities, delivered with a full set of examples.

The Universal Serial Bus (USB) is the most successful interconnect in the history of personal computing which is used to connect devices like mouse, game-pads and joysticks, scanners, digital cameras, and printers. USB has also migrated into consumer electronics and mobile products.

This user manual describes the STM32Cube™ USB device library which is part of the STM32Cube™ MCU Package that can be downloaded free from ST website (*http://www.st.com/stm32cube*). It is intended for developers who use STM32Cube™ MCU Package on STM32 microcontrollers. It describes how to start and implement a USB device applications for most common USB device classes (HID, MSC, Audio, CDC…) based on the USB device stack that supports all STM32 microcontroller Series.

Note: *This document is applicable to all STM32 Series that feature an USB peripheral. However for simplicity reason, the STM32F4xx devices and STM32CubeF4 are used as reference platform. To know more about the examples implementation on your STM32 device, refer to the readme file provided within the associated STM32Cube™ MCU package.*

Table 1. Application products

Type	Part numbers
STM32Cube MCU Packages	STM32CubeF0, STM32CubeF1, STM32CubeF2, STM32CubeF3, STM32CubeF4, STM32CubeF7, STM32CubeL0, STM32CubeL1, STM32CubeL4, STM32CubeG0, STM32CubeH7, STM32CubeWB

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1 Overview

1.1 Acronyms and abbreviations

Table 2 gives a brief definition of acronyms and abbreviations used in this document.

Table 2. List of terms

Term	Meaning
API	Application programming interface
CDC	Communication device class
DFU	Device firmware upgrade
FS	Full speed (12 Mbps)
HID	Human interface device
Mbps	Megabit per second
MSC	Mass storage class
OTG	On-The-Go: An OTG peripheral can switch Host/Device role on the fly
PID	USB product identifier
SCSI	Small computer system interface
SOF	Start of frame
VID	USB vendor identifier
USB	Universal serial bus

1.2 General information

STM32Cube™ USB device middleware runs on STM32 32-bit microcontrollers based on the Arm®[1] Cortex®-M processor.

1.3 Additional Information

In addition to this document STMicroelectronics provides several other resources related to the USB:

- USB Host library user manual (UM1720)
- Description of STM32F4xx HAL drivers (UM1725) where you can find the two USB generic drivers description (HCD for Host and PCD for Device)

1. Arm is a registered trademark of Arm Limited (or its subsidiaries) in the US and or elsewhere.

1.4 References

- Universal Serial Bus Specification, Revision 2.0, http: //www.usb.org
- USB device class specifications (Audio, HID, MSC, etc.): http://www.usb.org

2 USB device library description

2.1 Overview

STMicroelectronics offers to its customers new USB stacks (device stack and host stack) that support all STM32 MCUs together with many development tools such as *Atollic® TrueSTUDIO*, *IAR Embedded Workbench for ARM ®*, and Keil uVision®.

This document focuses on USB device stack. For the host stack, please refer to the related users manual.

The USB device library is generic for all STM32 microcontrollers, only the HAL layer is adapted to each STM32 device.

The USB device library comes on top of the STM32Cube™ USB device HAL driver and offers all the APIs required to develop a USB device application. The present document describes the STM32Cube™ USB device library middleware module and illustrates how the user can develop easily his own USB device application by using this library.

The USB device library is a part of STM32Cube™ package for each STM32 Series.

It contains:

- The USB low level driver
- Commonly used USB class drivers
- A set of applications for the most common USB device classes supporting USB Full speed and High speed transfer types (control, interrupt, bulk and isochronous).

The USB device library aim is to provide at least one firmware demonstration per USB transfer type:

- Human Interface Device HID

  HID Joystick demonstration based on the embedded joystick on the EVAL boards and Custom HID examples
- Audio streaming

  Audio device example for streaming audio data
- Communication Device (CDC)

  VCP USB-to-RS232 bridge to realize a virtual COM port.
- Mass storage

  Mass storage demonstration based on the microSD card available on the EVAL boards.
- Device Firmware Upgrade

  DFU for firmware downloads and uploads
- Dual Core devices demonstration

  Based on mass storage with Human interface and mass storage with CDC device examples

Among the topics covered are:

- USB device library architecture
- USB device library description
- USB device library state machine overview
- USB device classes overview.

2.2 Features

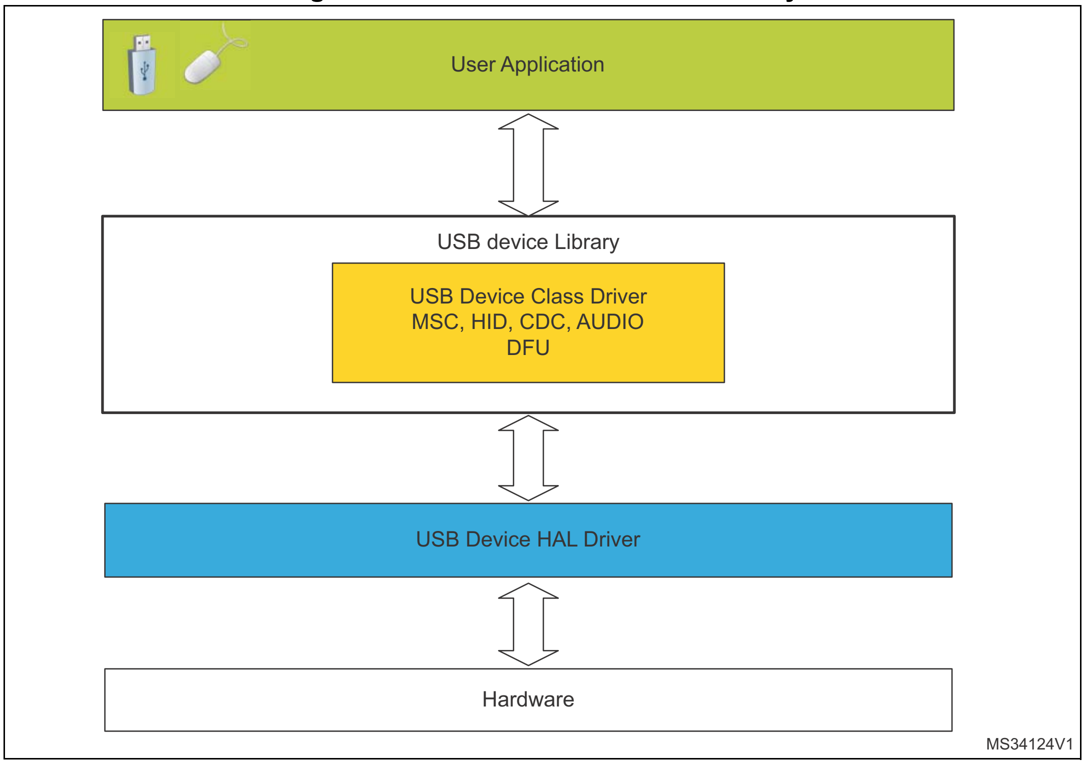
The main USB device library features are:

- Support of multi packet transfer features allowing sending big amount of data without splitting it into max packet size transfers.
- Support of up to 3 back to back transfers on control endpoints (compatible with OHCI controllers).
- Configuration files to change the core and the library configuration without changing the library code (Read Only).
- 32-bits aligned data structures to handle DMA based transfer in High speed modes.
- Support of multi USB OTG core instances from user level (configuration file).

Note: The USB device library can be used with or without RTOS; the CMSIS RTOS wrapper is used to make abstraction with OS kernel.

USB device examples do not display log messages.

Figure 1. STM32Cube USB device library



1. The user application is shown in green, the USB library core blocks in orange and the USB Device HAL driver in blue.

3 USB device library architecture

3.1 Architecture overview

The USB device library is mainly divided into three layers. The applications is developed on top of them as shown in *Figure 2: USB device library architecture*.

The first Layer is composed of the **core** and the **class** drivers.

- Core drivers

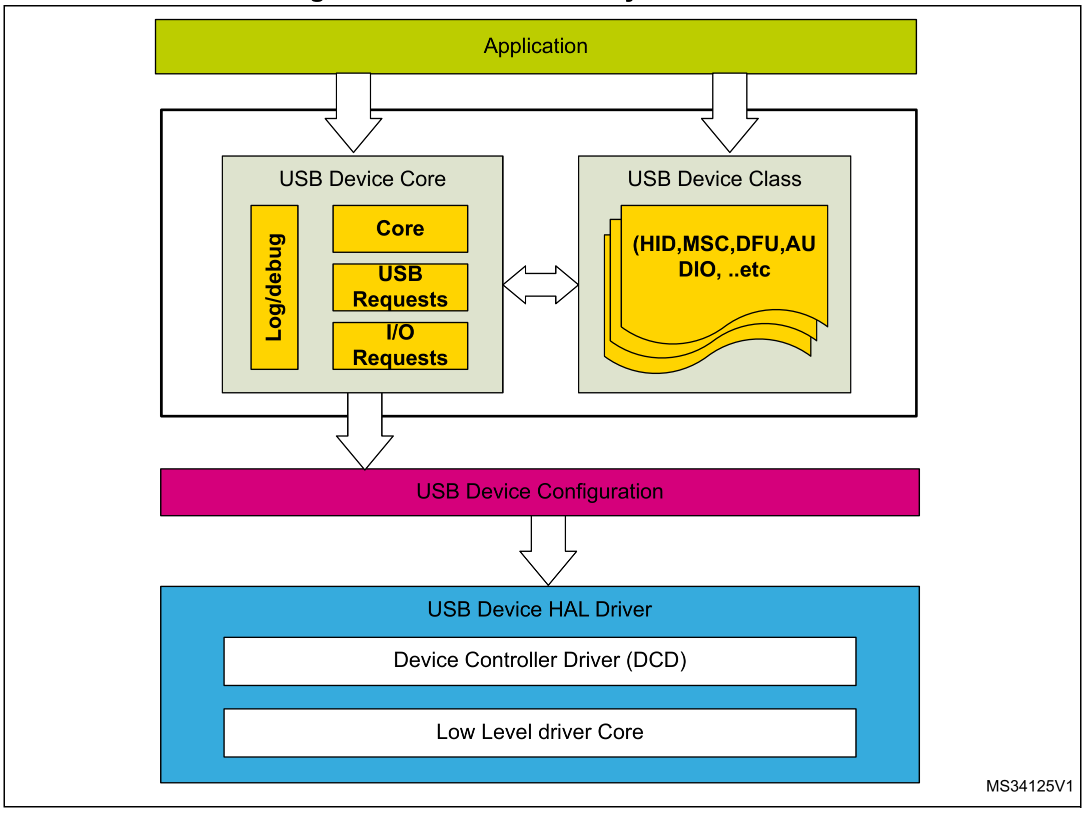
  The library core is composed of four main blocks:

  - USB core module that offers a full set of APIs to manage the internal USB device library state machine and call back processes from USB Interrupts
  - USB Requests module that handles chapter 9 requests
  - USB I/O requests module: handles low level I/O requests
  - USB Log and debug module that follows debug level *USB_DEBUG_LEVEL,* outputs user, log, error and debug messages.
- Class drivers

  The USB Device classes is composed of a set predefined class drivers ready to be linked to the USB core through the USBD_RegisterClass () routine.

The USB device library is a USB 2.0 compatible generic USB device stack, compliant with all the STM32 USB cores. It t can be easily linked to any USB HAL driver thanks to the configuration wrapper file which avoids any dependency between the USB library and the low level drivers.

Figure 2. USB device library architecture



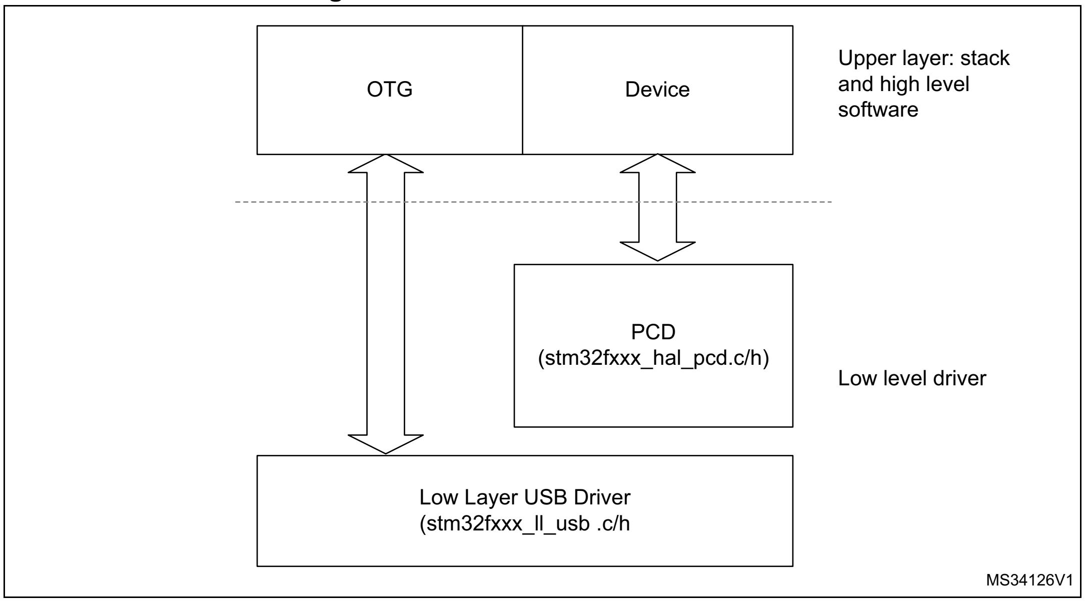
1. The USB library core blocks are shown in orange, the USB Device Configuration in magenta and the USB HAL driver in blue.

4 USB OTG Hardware Abstraction Layer

The low level driver can be used to connect the USB OTG core with the high level stack.

4.1 Driver architecture

Figure 3. Driver architecture overview


OTG
Device
Upper layer: stack and high level software
PCD (stm32fxxx_hal_pcd.c/h)
Low level driver
Low Layer USB Driver (stm32fxxx_ll_usb .c/h
MS34126V1

- The bottom layer (Low Layer USB driver) provides common APIs for device and OTG modes. It performs the core initialization in each mode and controls of the transfer flow.
- The Peripheral controller driver (PCD) layer provides an API for device mode access and the main interrupt routine for this mode.
- The OTG controller driver (OTG) layer provides an API for OTG mode access and the main interrupt routine for this mode.

Note: For more details on how to use the PCD driver, please refer to UM1725 that describes all PCD driver APIs.

4.2 USB driver programming manual

4.2.1 Configuring USB driver structure

Device initialization

The device is initialized using the following function contained in stm32fxxx_hal_pcd.c file:

HAL_StatusTypeDef HAL_PCD_Init(PCD_HandleTypeDef *hpcd)

Endpoint configuration

Once the USB core is initialized, the upper layer can call the low level driver to open or close the active endpoint and start transferring data. The following two APIs can be used:

HAL_StatusTypeDef **HAL_PCD_EP_Open**(PCD_HandleTypeDef *hpcd, uint8_t ep_addr, uint16_t ep_mps, uint8_t ep_type)

HAL_StatusTypeDef **HAL_PCD_EP_Close**(PCD_HandleTypeDef *hpcd, uint8_t ep_addr)

ep_addr, ep_mps and ep_type are respectively the endpoint address, the maximum data transfer and transfer type.

Device core structure

The main structure used in the device library is the device handle. Its type is "USBD_HandleTypedef" (see *Figure 4 on page 14*).

The USB Global device structure contains all the variables and structures used to keep all the information related to devices in real-time, as well as store the control transfer state machine and the endpoint information and status.

In this structure, dev_config holds the current USB device configuration and ep0_state controls the state machine with the following states:

```
/* EP0 State */
#define USBD_EP0_IDLE                    0
#define USBD_EP0_SETUP                   1
#define USBD_EP0_DATA_IN                 2
#define USBD_EP0_DATA_OUT                3
#define USBD_EP0_STATUS_IN               4
#define USBD_EP0_STATUS_OUT              5
#define USBD_EP0_STALL                   6
```

In this structure, `dev_state` defines the connection, configuration and power status:

```
/* Device Status */
#define USBD_DEFAULT                     1
#define USBD_ADDRESSED                   2
#define USBD_CONFIGURED                  3
#define USBD_SUSPENDED                   4
```

Note: *The USB specification (see Chapter 9) defines six USB device states:*

Attached*: the device is attached to the USB but is not powered by the USB.*

Powered*: the device is attached to the USB and has been powered but has not yet received any reset request.*

Default*: the device is attached to the USB. It is powered and reset, but no unique address has been assigned to it.*

Address*: the device is attached to the USB, it is powered and reset and has had a unique address assigned to it.*

Configured*: the device is already in address state and configured. It is not in suspend state.*

Suspended*: the device is attached and configured, but has not detected any activity on the bus for at least 3 ms.*

Figure 4. USBD_HandleTypedef

```
typedef struct _USBD_HandleTypeDef
{
  uint8_t                  id;
  uint32_t                 dev_config;
  uint32_t                 dev_default_config;
  uint32_t                 dev_config_status;
  USBD_SpeedTypeDef        dev_speed;
  USBD_EndpointTypeDef     ep_in[15];
  USBD_EndpointTypeDef     ep_out[15];
  uint32_t                 ep0_state;
  uint32_t                 ep0_data_len;
  uint8_t                  dev_state;
  uint8_t                  dev_old_state;
  uint8_t                  dev_address;
  uint8_t                  dev_connection_status;
  uint8_t                  dev_test_mode;
  uint32_t                 dev_remote_wakeup;
  USBD_SetupReqTypedef     request;
  USBD_DescriptorsTypeDef *pDesc;
  USBD_ClassTypeDef       *pClass;
  void                    *pClassData;
  void                    *pUserData;
  void                    *pData;
} USBD_HandleTypeDef;
```

USB data transfer flow

The PCD layer provides all the APIs required to start and control a transfer flow. This is done through the following set of functions:

HAL_StatusTypeDef HAL_PCD_EP_Transmit(PCD_HandleTypeDef *hpcd, uint8_t ep_addr, uint8_t *pBuf, uint32_t len)

HAL_StatusTypeDef HAL_PCD_EP_Receive(PCD_HandleTypeDef *hpcd, uint8_t ep_addr, uint8_t *pBuf, uint32_t len)

HAL_StatusTypeDef HAL_PCD_EP_SetStall(PCD_HandleTypeDef *hpcd, uint8_t ep_addr)

HAL_StatusTypeDef HAL_PCD_EP_ClrStall(PCD_HandleTypeDef *hpcd, uint8_t ep_addr)

HAL_StatusTypeDef HAL_PCD_EP_Flush(PCD_HandleTypeDef *hpcd, uint8_t ep_addr)

The PCD layer contains one function that must be called by the USB interrupt:

void HAL_PCD_IRQHandler(PCD_HandleTypeDef *hpcd)

The stm32fxxx_hal_pcd.*h* file contains the function prototypes called from the library core layer to handle the USB events.

Important enumerated typedefs

- USBD_StatusTypeDef

  Almost all library functions return a status of type USBD_StatusTypeDef. The user application should always check the returned status.

```
typedef enum
{
  USBH_OK    = 0,
  USBH_BUSY,
  USBH_FAIL,
}USBH_StatusTypeDef;
```

Table 3 describes the possible returned status:

Table 3. USB device status

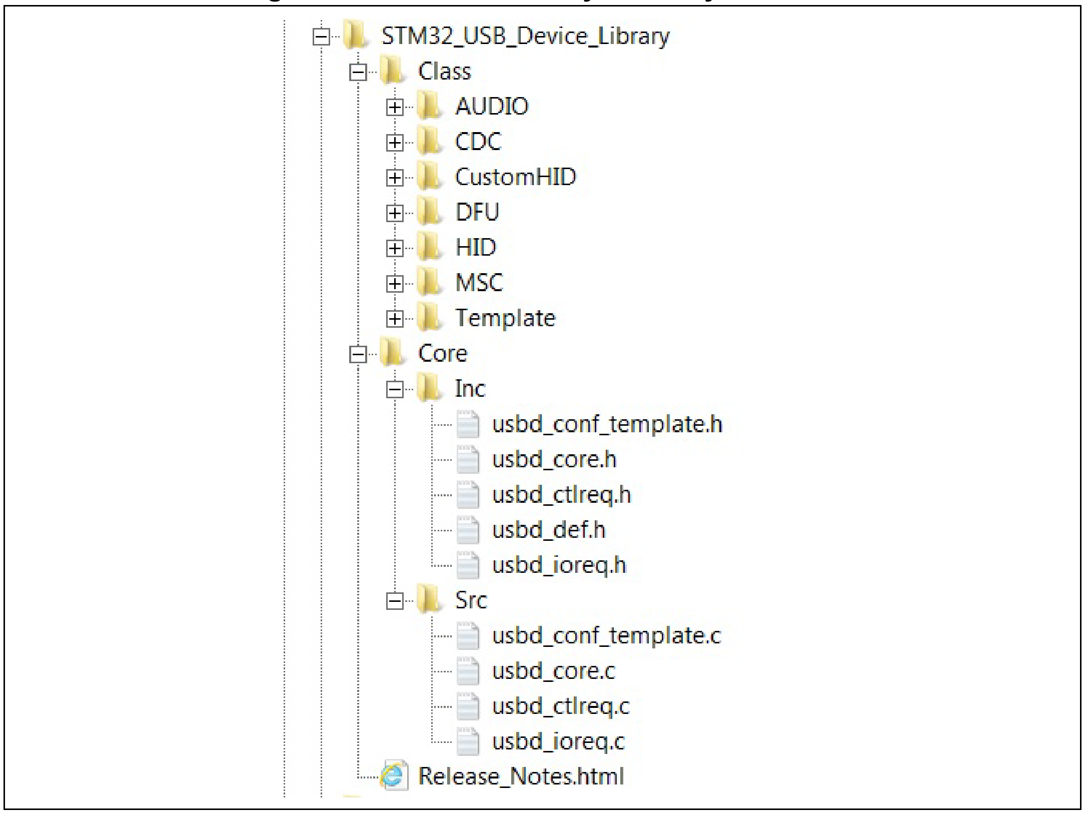
Status	Description
USBH_OK	Returned when operation is completed successfully.
USBH_BUSY	Returned when operation is still not completed (busy).
USBH_FAIL	Returned when operation has failed due to a low level error or protocol fail.

5 USB device library overview

The USB device library is based on the generic USB low level driver. It has been developed to work in Full speed and High speed mode.

It implements the USB device library machines as defined by *Universal Serial Bus Specification* revision *2.0*. The library functions are covered by the files located in the **Core** folder within the USB device library firmware package (see *Figure 5*). The USB class module is the class layer built in compliance with the protocol specification.

Figure 5. USB device library directory structure



```
STM32_USB_Device_Library
  Class
    AUDIO
    CDC
    CustomHID
    DFU
    HID
    MSC
    Template
  Core
    Inc
      usbd_conf_template.h
      usbd_core.h
      usbd_ctlreq.h
      usbd_def.h
      usbd_ioreq.h
    Src
      usbd_conf_template.c
      usbd_core.c
      usbd_ctlreq.c
      usbd_ioreq.c
  Release_Notes.html
```

5.1 USB device library description

5.1.1 USB device library flow

Handling control endpoint

The USB specification defines four transfer types: control, interrupt, bulk and isochronous. The USB host sends requests to the device through the control endpoint (in this case, control endpoint is endpoint 0). The requests are sent to the device as SETUP packets. These requests can be classified into three categories: standard, class-specific and vendor-specific. Since the standard requests are generic and common to all USB devices, the library receives and handles all the standard requests on the control endpoint 0.

The format and the meaning of the class-specific requests and the vendor specific requests are not common for all USB devices.

All SETUP requests are processed with a state machine implemented in an interrupt model. An interrupt is generated at the end of the correct USB transfer. The library code receives this interrupt. In the interrupt process routine, the trigger endpoint is identified. If the event is a setup on endpoint 0, the payload of the received setup is saved and the state machine starts.

Transactions on non-control endpoint

The class-specific core uses non-control endpoints by calling a set of functions to send or receive data through the data IN and OUT stage callbacks.

Data structure for the SETUP packet

When a new SETUP packet arrives, all the eight bytes of the SETUP packet are copied to an internal structure *USB_SETUP_REQ req*, so that the next SETUP packet cannot overwrite the previous one during processing. This internal structure is defined as:

Figure 6. Data structure for SETUP packet

```
typedef  struct  usb_setup_req
{
    uint8_t   bmRequest;
    uint8_t   bRequest;
    uint16_t  wValue;
    uint16_t  wIndex;
    uint16_t  wLength;
}USBD_SetupReqTypedef;
```

Standard requests

Most of the requests specified in *Table 4* of the USB specification are handled as standard requests in the library. *Table 4* lists all the standard requests and their valid parameters in the library. Requests that are not in *Table 4* are considered as non-standard requests.

Table 4. Standard requests

-	State	bmRequestType	Low byte of *wValue*	High byte of *wValue*	Low byte of *wIndex*	High byte of *wIndex*	wLength	Comments
GET_STATUS	A, C	80	00	00	00	00	2	Gets the status of the Device.
	C	81	00	00	N	00	2	Gets the status of Interface, where N is the valid interface number.
	A, C	82	00	00	00	00	2	Gets the status of endpoint 0 OUT direction.
	A, C	82	00	00	80	00	2	Gets the status of endpoint 0 IN direction.
	C	82	00	00	EP	00	2	Gets the status of endpoint EP.

Table 4. Standard requests (continued)

-	State	bmRequestType	Low byte of *wValue*	High byte of *wValue*	Low byte of *wIndex*	High byte of *wIndex*	wLength	Comments
CLEAR_FEATURE	A, C	00	01	00	00	00	00	Clears the device remote wakeup feature.
	C	02	00	00	EP	00	00	Clears the STALL condition of endpoint EP. EP does not refer to endpoint 0.
SET_FEATURE	A, C	00	01	00	00	00	00	Sets the device remote wakeup feature.
	C	02	00	00	EP	00	00	Sets the STALL condition of endpoint EP. EP does not refer to endpoint 0.
SET_ADDRESS	D, A	00	N	00	00	00	00	Sets the device address, N is the valid device address.
GET_DESCRIPTOR	All	80	00	01	00	00	Non-0	Gets the device descriptor.
	All	80	N	02	00	00	Non-0	Gets the configuration descriptor; where N is the valid configuration index.
	All	80	N	03	LangID		Non-0	Gets the string descriptor; where N is the valid string index. This request is valid only when the string descriptor is supported.
GET_CONFIGURATION	A, C	80	00	00	00	00	1	Gets the device configuration.
SET_CONFIGURATION	A, C	80	N	00	00	00	00	Sets the device configuration; where N is the valid configuration number.
GET_INTERFACE	C	81	00	00	N	00	1	Gets the alternate setting of the interface N; where N is the valid interface number.
SET_INTERFACE	C	01	M	00	N	00	00	Sets alternate setting M of the interface N; where N is the valid interface number and M is the valid alternate setting of the interface N.

Note: *In column State: D = Default state; A = Address state; C = Configured state; All = All states. EP: D0-D3 = endpoint address; D4-D6 = Reserved as zero; D7= 0: OUT endpoint, 1: IN endpoint.*

Non-standard requests

All the non-standard requests are passed to the class specific code through callback functions.

- SETUP stage

  The library passes all the non-standard requests to the class-specific code with the callback *pdev->pClass->Setup (pdev, req)* function.

  The non-standard requests include the user-interpreted requests and the invalid requests. User-interpreted requests are class- specific requests, vendor-specific requests or the requests that the library considers as invalid requests that the application wants to interpret as valid requests

  Invalid requests are the requests that are not standard requests and are not user-interpreted requests. Since *pdev->pClass->Setup (pdev, req)* is called after the SETUP stage and before the data stage, user code is responsible, in the **pdev->pClass->Setup (pdev, req)** to parse the content of the SETUP packet (req). If a request is invalid, the user code has to call **USBD_CtlError(pdev , req)** and return to the caller of **pdev->pClass->Setup (pdev, req)**

  For a user-interpreted request, the user code prepares the data buffer for the following data stage if the request has a data stage; otherwise the user code executes the request and returns to the caller of pdev->pClass->Setup (pdev, req).

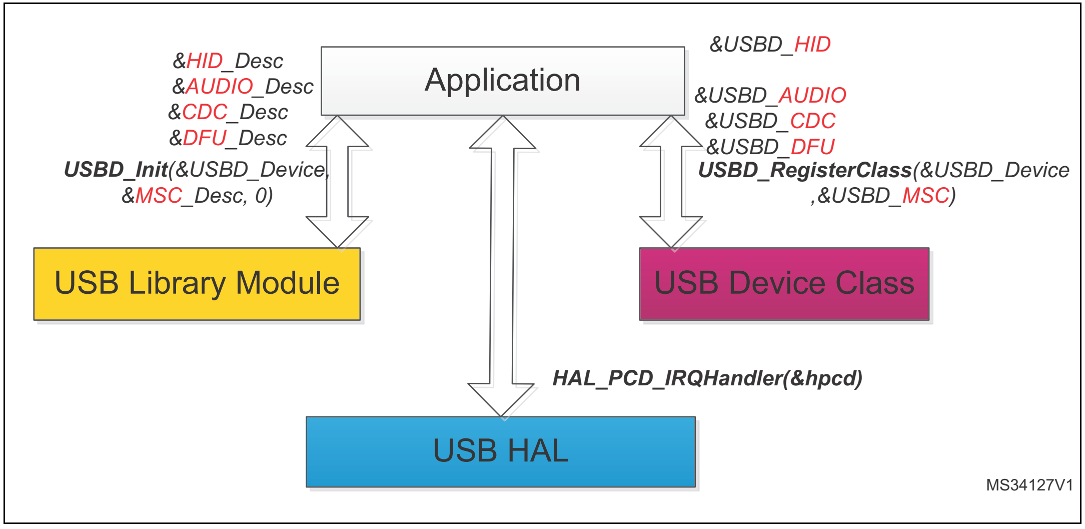
- DATA stage

  The class layer uses the standard USBD_CtlSendData and USBD_CtlPrepareRx to send or receive data. The data transfer flow is handled internally by the library and the user does not need to split the data in ep_size packet.

- Status stage

  The status stage is handled by the library after returning from the pdev->pClass->Setup (pdev, req) callback.

Figure 7. USB device library process flowchart



1. The red text identifies the USB device configuration.

As shown in the *Figure 7: USB device library process flowchart*, only the following modules are necessary for USB programming: USB library, USB Device class and main application.

The main application executes the user defined program. **main.c, stm32fxx_it.c, usbd_conf.c** and **usbd_desc.c** together with their header files are the main files (mandatory for the application) that the user needs to develop his own application. The user can modify them according to his application requirements (class driver).

Only simple APIs are called. They allows interfacing between the application layer and the USB library module which handles the USB initialization and getting the current status of the USB.

To initialize the USB HAL driver, the USB device library and the hardware on the used board (BSP) and to start the library, the user application must call these three APIs:

- **USBD_Init ():** This function initializes the device stack and loads the class driver.
  The device descriptor is stored in the *usbd_desc.c* and *usbd_desc.h* (used for the configuration descriptor type) files:
- **USBD_RegisterClass():** This function links the class driver to the device core.
- **USBD_Start():** This function allows user to start the USB device core

For example the user can add additional endpoints in the **usbd_conf** file**,** depending on the class requirement. This is done by calling USBD_LL_Init() function. The *dev_endpoints* should contain the number of required endpoints following the USB class specifications.

The USB device library provides several configurations thanks to the *usbd_conf.h* file (for more details refer to *Section 5.1.5: Configuring the USB device firmware library on page 23*).

Note: The HAL library initialization is done through the HAL_Init() API in the stm32fxxx_hal.c This *function performs the following operation:*

- Reset of all peripherals

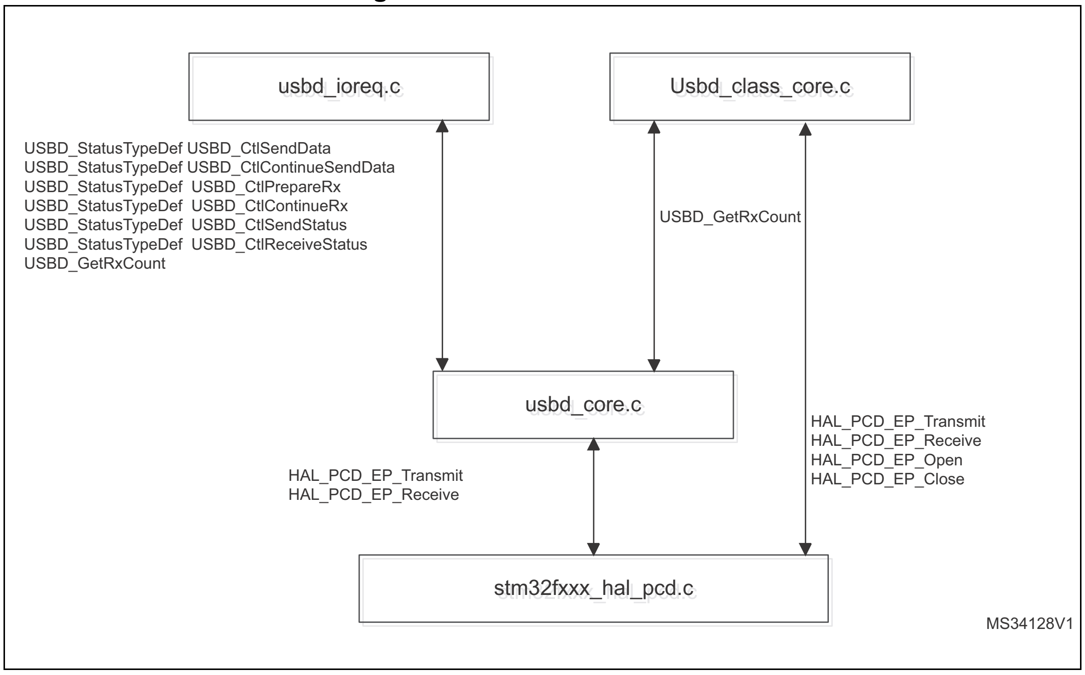
- Configuration of Flash prefetch, Instruction cache, Data cache

- Enabling of SysTick and configuration of 1 ms tick (default clock after Reset is HSI)

5.1.2 USB device data flow

The USB library (USB core and USB class layer) handles the data processing on endpoint 0 (EP0) through the I/O request layer when a wrapping is needed to manage the multi-packet feature on the control endpoint, or directly from the stm32fxxx_hal_pcd layer when the other endpoints are used since the USB OTG core supports the multi-packet feature. *Figure 8* illustrates this data flow scheme.

Figure 8. USB device data flow


usbd_ioreq.c
Usbd_class_core.c
USBD_StatusTypeDef USBD_CtlSendData
USBD_StatusTypeDef USBD_CtlContinueSendData
USBD_StatusTypeDef USBD_CtlPrepareRx
USBD_StatusTypeDef USBD_CtlContinueRx
USBD_StatusTypeDef USBD_CtlSendStatus
USBD_StatusTypeDef USBD_CtlReceiveStatus
USBD_GetRxCount
USBD_GetRxCount
usbd_core.c
HAL_PCD_EP_Transmit
HAL_PCD_EP_Receive
HAL_PCD_EP_Open
HAL_PCD_EP_Close
HAL_PCD_EP_Transmit
HAL_PCD_EP_Receive
stm32fxxx_hal_pcd.c
MS34128V1

5.1.3 Core interface with low level driver

As mentioned before, the USB device library interfaces with the STM32Cube™ HAL low layer drivers using a low level interface layer which acts as a link layer with the STM32Cube™ HAL.

The low level interface implements low level API functions and calls some library core callback functions following some USB events.

In the STM32Cube™ package, the implementation of the low level interface is provided as part of the USB device examples since some parts of the low level interface are board and system dependent.

Table 5 lists the low level API functions:

Note: *These APIs are provided by the USB Device Configuration file (usbd_conf.c). They should be implemented in the user files and adapted to the USB Device Controller Driver.*

The user can start from the usbd_conf.c file provided within STM32Cube™ package. This file can also be copied to the application folder and modified depending on the application needs.

Table 5. API description

API	Description
USBD_LL_Init	Low level initialization.
USBD_LL_DeInit	Low level de-initialization.
USBD_LL_Start	Low level start.
USBH_LL_Stop	Low level stop.
USBD_LL_OpenEP	Initializes an endpoint.

Table 5. API description (continued)

API	Description
USBD_LL_CloseEP	Closes and de-initializes an endpoint state.
USBD_LL_FlushEP	Flushes an endpoint of the Low Level Driver.
USBD_LL_StallEP	Sets a Stall condition on an endpoint of the Low Level Driver.
USBD_LL_ClearStallEP	Clears a Stall condition on an endpoint of the Low Level Driver.
USBD_LL_IsStallEP	Returns Stall condition.
USBD_LL_SetUSBAddress	Assigns an USB address to the device.
USBD_LL_Transmit	Transmits data over an endpoint.
USBD_LL_PrepareReceive	Prepares an endpoint for reception.
USBD_LL_GetRxDataSize	Returns the last transferred packet size.

5.1.4 USB device library interfacing model

The USB device library is built around central generic and portable class modules.

Figure 9. USB device library interfacing model

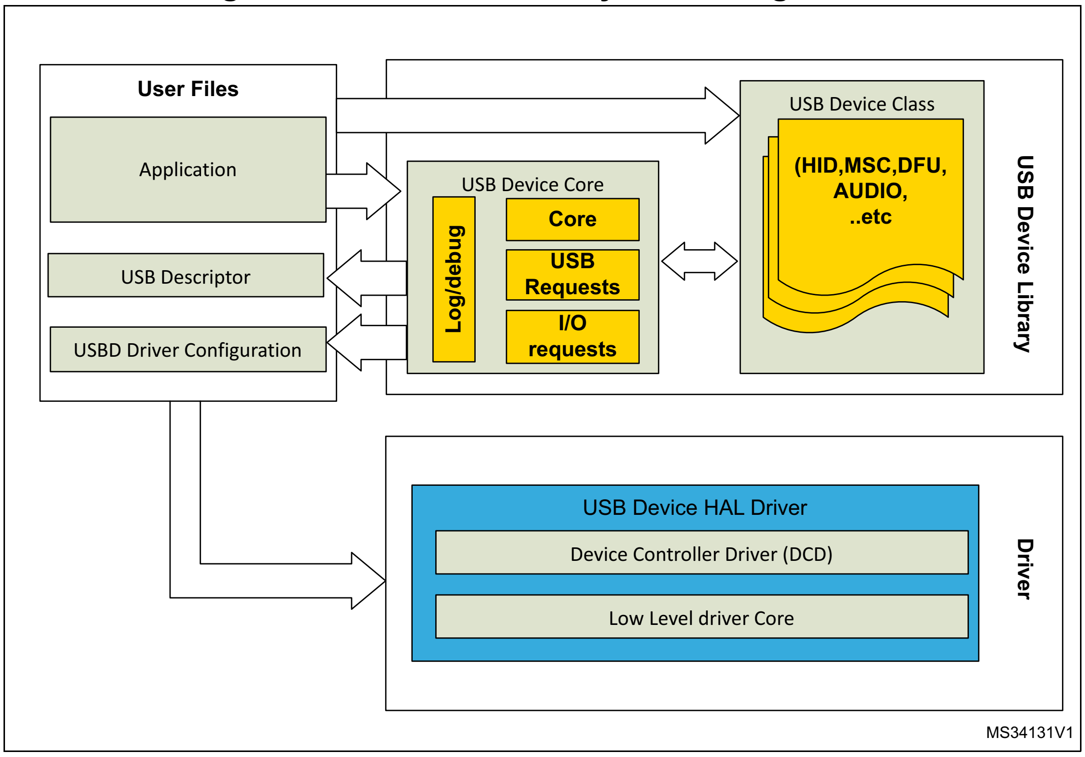


Table 6 shows all the device library callback functions which are called from the low level interface following some USB events.

Table 6. Low level Event Callback functions

Callback functions	Description
HAL_PCD_ConnectCallback	Device connection Callback.
HAL_PCD_DataInStageCallback	Data IN stage Callback.
HAL_PCD_DataInStageCallback	Data OUT stage Callback.
HAL_PCD_DisconnectCallback	Disconnection Callback.
HAL_PCD_ISOINIncompleteCallback	ISO IN transaction Callback.
HAL_PCD_ISOINIncompleteCallback	ISO OUT transaction Callback.
HAL_PCD_ResetCallback	USB Reset Callback.
HAL_PCD_ResumeCallback	USB Resume Callback.
HAL_PCD_SetupStageCallback	Setup stage Callback.
HAL_PCD_SOFCallback	Start Of Frame callback.
HAL_PCD_SuspendCallback	Suspend Callback.

5.1.5 Configuring the USB device firmware library

The USB device library can be configured using the *usbd_conf.h* file.

The **usbd_conf.h** is a specific configuration file used to define some global parameters and specific configurations. This file is used to link the upper library with the HAL drivers and the BSP drivers.

Table 7. USB library configuration

item	Parameter	Description
Common configuration	USBD_MAX_NUM_CONFIGURATION	Maximum number of supported configurations [1 to 255].
	USBD_MAX_NUM_INTERFACES	Maximum number of supported Interfaces [1 to 255].
	USBD_MAX_STR_DESC_SIZ	Maximum size of string descriptors [uint16].
	USBD_SELF_POWERED	Enables self power feature [0/1].
	USBD_DEBUG_LEVEL	Debug and log level.
	USBD_SUPPORT_USER_STRING	Enables user string support[0/1].
Mass Storage configuration	MSC_MEDIA_PACKET	Media I/O buffer size multiple of 512 bytes [512 to 32 Kbytes].
HID Configuration	NA	NA.

Table 7. USB library configuration (continued)

item	Parameter	Description
DFU Configuration	USBD_DFU_MAX_ITF_NUM	Maximum media interface number [1 to 255].
	USBD_DFU_XFER_SIZE	Media I/O buffer size multiple of 512 bytes [512 to 32 Kbytes].
	USBD_DFU_APP_DEFAULT_ADD	Application address (0x0800C000).
CDC Configuration	NA	NA.
Audio Configuration	USBD_AUDIO_FREQ	8 to 48 KHz.

Note: The user can start from the usbd_conf.c file provided within STM32Cube™ package. This file could be also copied to the application folder and modified depending on the application needs.

By default for USB device examples, library and user messages ***are not displayed*** *on the LCD.*

However the user can implement his own messages. To redirect the library messages on the LCD screen, lcd_log.c driver must be added to the application sources. He can choose to display them or not by modifying define values in the usbd_conf.h configuration file available under the project includes directory. For example:

0: No Log/Debug messages

1: log messages enabled

2: log and debug messages enabled

5.1.6 USB control functions

Device reset

When the device receives a reset signal from the USB, the library resets and initializes both application software and hardware. This function is part of the interrupt routine.

Device suspend

When the device detects a suspend condition on the USB, the library stops all the ongoing operations and puts the system in suspend state (if low power mode management is enabled in the *usbd_conf.c* file).

Device resume

When the device detects a resume signal on the USB, the library restores the USB core clock and puts the system in idle state (if low power mode management is enabled in the *usbd_conf.c* file).

5.2 USB device library functions

The ***Core*** folder contains the USB device library machines as defined by the Universal Serial Bus Specification, revision 2.0.

Table 8. USB device core files

File	Description
usbd_core (.c, .h)	This file contains the functions for handling all USB communication and state machine.
usbd_req(.c,.h)	This file includes the requests implementation listed in Chapter 9 of the specification.
usbd_ctlreq(.c,.h)	This file handles the results of the USB transactions.
usbd_conf_template(.c,.h)	Template file for the low layer interface file, should be customized by user and included with application file.
usbd_def(.c, .h)	Common library defines.

The ***Class*** folder contains all the files relative to the class implementation and complies with the specification of the protocol built in these classes.

Table 9. Class drivers files

USB class	file	Description
Mass-Storage	usbh_msc (.c,.h)	Mass-storage class handler.
	usbh_msc_bot(.c,.	Bulk-only transfer protocol handler.
	usbh_msc_scsi(.c,.h)	SCSI commands.
	usbd_msc_data (.c,.h)	Vital inquiry pages and sense data.
HID Joystick mouse	usbh_hid(.c,.h	HID class state handler.
Audio speaker	usbh_audio(.c,.h)	Audio class handler.
Audio speaker	usbh_cdc(.c,.h)	CDC virtual comport handler.
Custom HID	usbd_customhid(.c,.h)	Custom HID Class Handler.
DFU Class	usbd_dfu(.c,.h)	DFU class handler.

Table 10. usbd_core (.c,.h) files

Functions	Description
USBD_StatusTypeDef USBD_Init(USBD_HandleTypeDef *pdev, USBD_DescriptorsTypeDef *pdesc, uint8_t id)	Initializes the device library and loads the class driver and the user call backs.
USBD_StatusTypeDef USBD_DeInit(USBD_HandleTypeDef *pdev)	De-Initializes the device library.
USBD_StatusTypeDef USBD_RegisterClass(USBD_HandleTypeDef *pdev, USBD_ClassTypeDef *pclass)	Loads the class driver.

Table 10. usbd_core (.c,.h) files (continued)

Functions	Description
USBD_StatusTypeDef USBD_Start (USBD_HandleTypeDef *pdev)	Starts the device library process.
USBD_StatusTypeDef USBD_Stop (USBD_HandleTypeDef *pdev)	Stops the device library process and frees related resources.
USBD_StatusTypeDef USBD_LL_SetupStage(USBD_HandleTypeDef *pdev, uint8_t *psetup)	Handles setup stage from ISR.
USBD_StatusTypeDef USBD_LL_DataOutStage(USBD_HandleTypeDef *pdev , uint8_t epnum, uint8_t *pdata)	Handles data out stage from ISR.
USBD_StatusTypeDef USBD_LL_DataInStage(USBD_HandleTypeDef *pdev ,uint8_t epnum, uint8_t *pdata)	Handles data IN stage.
USBD_StatusTypeDef USBD_LL_Reset(USBD_HandleTypeDef *pdev)	Handles USB Reset from ISR.
USBD_StatusTypeDef USBD_LL_SetSpeed(USBD_HandleTypeDef *pdev, USBD_SpeedTypeDef speed)	Sets USB Core Speed
USBD_StatusTypeDef USBD_LL_Suspend(USBD_HandleTypeDef *pdev)	Handles Suspend Event.
USBD_StatusTypeDef USBD_LL_Resume(USBD_HandleTypeDef *pdev)	Handles Resume event.
USBD_StatusTypeDef USBD_LL_SOF(USBD_HandleTypeDef *pdev);	Handles Start Of Frame Event.
USBD_StatusTypeDef USBD_LL_IsoINIncomplete(USBD_HandleTypeDef *pdev, uint8_t epnum)	Handles Incomplete ISO IN transaction Event.
USBD_StatusTypeDef USBD_LL_IsoOUTIncomplete(USBD_HandleTypeDef *pdev, uint8_t epnum)	Handles Incomplete ISO OUT transaction Event.
USBD_StatusTypeDef USBD_LL_DevConnected(USBD_HandleTypeDef *pdev)	Notifies about device connection from ISR.
USBD_StatusTypeDef USBD_LL_DevDisconnected(USBD_HandleTypeDef *pdev)	Notifies about device disconnection from ISR.

Table 11. usbd_ioreq (.c,.h) files functions

Functions	Description
USBD_StatusTypeDef USBD_CtlSendData (USBD_HandleTypeDef *pdev, uint8_t *pbuf,uint16_t len)	Sends the data on the control pipe.

Table 11. usbd_ioreq (.c,.h) files functions (continued)

Functions	Description
USBD_StatusTypeDef USBD_CtlContinueSendData (USBD_HandleTypeDef *pdev, uint8_t *pbuf, uint16_t len)	Continues sending data on the control pipe.
USBD_StatusTypeDef USBD_CtlPrepareRx (USBD_HandleTypeDef *pdev,uint8_t *pbuf, uint16_t len)	Prepares the core to receive data on the control pipe.
USBD_StatusTypeDef USBD_CtlContinueRx (USBD_HandleTypeDef *pdev, uint8_t *pbuf, uint16_t len)	Continues receiving data on the control pipe.
USBD_StatusTypeDef USBD_CtlSendStatus (USBD_HandleTypeDef *pdev)	Sends a zero length packet on the control pipe.
USBD_StatusTypeDef USBD_CtlReceiveStatus (USBD_HandleTypeDef *pdev)	Receives a zero length packet on the control pipe.
uint16_t USBD_GetRxCount (USBD_HandleTypeDef *pdev , uint8_t ep_addr)	Returns the received data length.

Table 12. usbd_ctrlq (.c,.h) files functions

Functions	Description
USBD_StatusTypeDef USBD_StdDevReq (USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req)	Handles standard USB device requests.
USBD_StatusTypeDef USBD_StdItfReq (USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req)	Handles standard USB interface requests.
USBD_StatusTypeDef USBD_StdEPReq (USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req)	Handles standard USB endpoint requests.
static void USBD_GetDescriptor(USBD_HandleTypeDef *pdev ,USBD_SetupReqTypedef *req)	Handles Get Descriptor requests.
static void USBD_SetAddress(USBD_HandleTypeDef *pdev , USBD_SetupReqTypedef *req)	Sets new USB device address.
static void USBD_SetConfig(USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req)	Handles Set device configuration request.
static void USBD_GetConfig(USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req)	Handles Get device configuration request.
static void USBD_GetStatus(USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req)	Handles Get Status request.
static void USBD_SetFeature(USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req)	Handles Set device feature request.
static void USBD_ClrFeature(USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req)	Handles Clear device feature request.
void USBD_CtlError(USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req)	Handles USB Errors on the control pipe.

Table 12. usbd_ctrlq (.c,.h) files functions (continued)

Functions	Description
void USBD_GetString(uint8_t *desc, uint8_t *unicode, uint16_t *len)	Converts ASCII string into unicode one.
static uint8_t USBD_GetLen(uint8_t *buf)	Returns the string length.
void USBD_ParseSetupRequest (USBD_SetupReqTypedef *req, uint8_t *pdata)	Copies request buffer into setup structure.

5.3 USB device class interface

USB Class callback structure

The USB class is chosen during the USB device library initialization by selecting the corresponding class callback structure. The class structure is defined as follows:

Figure 10. USB Class callback structure

```
typedef struct _Device_cb
{
  uint8_t  (*Init)             (struct _USBD_HandleTypeDef *pdev ,
uint8_t cfgidx);
  uint8_t  (*DeInit)           (struct _USBD_HandleTypeDef *pdev ,
uint8_t cfgidx);
 /* Control Endpoints*/
  uint8_t  (*Setup)            (struct _USBD_HandleTypeDef *pdev ,
USBD_SetupReqTypedef  *req);
  uint8_t  (*EP0_TxSent)      (struct _USBD_HandleTypeDef *pdev );
  uint8_t  (*EP0_RxReady)      (struct _USBD_HandleTypeDef *pdev );
  /* Class Specific Endpoints*/
  uint8_t  (*DataIn)           (struct _USBD_HandleTypeDef *pdev ,
uint8_t epnum);
  uint8_t  (*DataOut)          (struct _USBD_HandleTypeDef *pdev ,
uint8_t epnum);
  uint8_t  (*SOF)              (struct _USBD_HandleTypeDef *pdev);
  uint8_t  (*IsoINIncomplete)  (struct _USBD_HandleTypeDef *pdev ,
uint8_t epnum);
  uint8_t  (*IsoOUTIncomplete) (struct _USBD_HandleTypeDef *pdev ,
uint8_t epnum);
  uint8_t  *(*GetHSConfigDescriptor)(uint16_t *length);
  uint8_t  *(*GetFSConfigDescriptor)(uint16_t *length);
  uint8_t  *(*GetOtherSpeedConfigDescriptor)(uint16_t *length);
  uint8_t  *(*GetDeviceQualifierDescriptor)(uint16_t *length);
} USBD_ClassTypeDef;
```

- ***Init***: this callback is called when the device receives the set configuration request; in this function the endpoints used by the class interface are open.
- ***DeInit***: This callback is called when the clear configuration request has been received; this function closes the endpoints used by the class interface.

- ***Setup***: This callback is called to handle the specific class setup requests.
- ***EP0_TxSent***: This callback is called when the send status is finished.
- ***EP0_RxSent***: This callback is called when the receive status is finished.
- ***DataIn***: This callback is called to perform the data in stage relative to the non-control endpoints.
- ***DataOut***: This callback is called to perform the data out stage relative to the non-control endpoints.
- ***SOF***: This callback is called when a SOF interrupt is received; this callback can be used to synchronize some processes with the SOF.
- ***IsoINIncomplete***: This callback is called when the last isochronous IN transfer is incomplete.
- ***IsoOUTIncomplete***: This callback is called when the last isochronous OUT transfer is incomplete.
- ***GetHSConfigDescriptor:*** This callback returns the HS USB Configuration descriptor.
- ***GetFSConfigDescriptor:*** This callback returns the FS USB Configuration descriptor.
- ***GetOtherSpeedConfigDescriptor:*** This callback returns the other configuration descriptor of the used class in High Speed mode.
- ***GetDeviceQualifierDescriptor:*** This callback returns the Device Qualifier Descriptor.

USB device descriptors structure

The library provides also descriptor callback structures that allow user to manage the device and string descriptors at application run time. This descriptors structure is defined as follows:

Figure 11. USB device descriptors structure

```
typedef struct
{
  uint8_t  *(*GetDeviceDescriptor)( USBD_SpeedTypeDef speed ,
uint16_t *length);
  uint8_t  *(*GetLangIDStrDescriptor)( USBD_SpeedTypeDef speed ,
uint16_t *length);
  uint8_t  *(*GetManufacturerStrDescriptor)( USBD_SpeedTypeDef speed
, uint16_t *length);
  uint8_t  *(*GetProductStrDescriptor)( USBD_SpeedTypeDef speed ,
uint16_t *length);
  uint8_t  *(*GetSerialStrDescriptor)( USBD_SpeedTypeDef speed ,
uint16_t *length);
  uint8_t  *(*GetConfigurationStrDescriptor)( USBD_SpeedTypeDef speed
, uint16_t *length);
  uint8_t  *(*GetInterfaceStrDescriptor)( USBD_SpeedTypeDef speed ,
uint16_t *length);
} USBD_DescriptorsTypeDef;
```

- ***GetDeviceDescriptor***: This callback returns the device descriptor.
- ***GetLangIDStrDescriptor***: This callback returns the Language ID string descriptor.

- ***GetManufacturerStrDescriptor***: This callback returns the manufacturer string descriptor.
- ***GetProductStrDescriptor***: This callback returns the product string descriptor.
- ***GetSerialStrDescriptor***: This callback returns the serial number string descriptor.
- ***GetConfigurationStrDescriptor***: This callback returns the configuration string descriptor.
- ***GetInterfaceStrDescriptor***: This callback returns the interface string descriptor.

Note: The usbd_desc.c file provided within USB Device examples implements these callback bodies.

6 USB device library class module

The class module contains all the files related to the class implementation. It complies with the specification of the protocol built in these classes. *Table 13* shows the USB device class files for the MSC, HID, DFU, Audio, CDC classes.

Table 13. USB device class files

Class	Files	Description
HID	usbd_hid (.c, .h)	This file contains the HID class callbacks (driver) and the configuration descriptors relative to this class.
MSC	usbd_msc(.c, .h)	This file contains the MSC class callbacks (driver) and the configuration descriptors relative to this class.
	usbd_bot (.c, .h)	This file handles the bulk only transfer protocol.
	usbd_scsi (.c, .h)	This file handles the SCSI commands.
	usbd_msc_data (.c,.h)	This file contains the vital inquiry pages and the sense data of the mass storage devices.
	usbd_msc_storage_template (.c,.h)	This file provides a template driver which allows you to implement additional functions for MSC.
DFU	usbd_dfu (.c,.h)	This file contains the DFU class callbacks (driver) and the configuration descriptors relative to this class.
	usbd_dfu_media_template_if (.c,.h)	This file provides a template driver which allows you to implement additional memory interfaces.
Audio	usbd_audio (.c,.h)	This file contains the AUDIO class callbacks (driver) and the configuration descriptors relative to this class.
	usbd_audio_if_template (.c,.h)	This file provides a template driver which allows you to implement additional functions for Audio.
CDC	usbd_cdc (.c,.h)	This file contains the CDC class callbacks (driver) and the configuration descriptors relative to this class.
	usbd_cdc_if_template (.c,.h)	This file provides a template driver which allows you to implement low layer functions for a CDC terminal.
Custom HID	usbd_customhid (.c,.h)	This file contains the Custom HID class callbacks (driver) and the configuration descriptors relative to this class.

6.1 HID class

6.1.1 HID class implementation

This module manages the HID class V1.11 following the “Device Class Definition for Human Interface Devices (HID) Version 1.11 June 27, 2001".

The HID specification can be found searching for “hidpage” on www.st.com.

This driver implements the following aspects of the specification:

- The boot interface subclass
- The mouse protocol
- Usage page: generic desktop
- Usage: joystick
- Collection: application

6.1.2 HID user interface

Input reports are sent only via the **Interrupt In** pipe (HID mouse example).

Feature and Output reports must be initiated by the host via Control pipe or an Interrupt Out pipe (Custom HID example)

The `USBD_HID_SendReport` can be used by the HID mouse application to send HID reports, the HID driver, in this release, handles only IN traffic. An example of use of this function is shown below:

Figure 12. Example of USBD_HID_SendReport function

```
  static __IO uint32_t counter=0;
  HAL_IncTick();
  /* check Joystick state every 10ms */
  if (counter++ == 10)
  {
    GetPointerData(HID_Buffer);
    /* send data though IN endpoint*/
    if((HID_Buffer[1] != 0) || (HID_Buffer[2] != 0))
    {
      USBD_HID_SendReport(&USBD_Device, HID_Buffer, 4);
    }
    counter =0;
  }
  Toggle_Leds();
}
```

6.1.3 HID Class Driver APIs

All HID class driver APIs are defined in usbd_hid.c and summarized in the table below.

Table 14. usbd_hid.c,h files

Functions	Description
static uint8_t USBD_HID_Init (USBD_HandleTypeDef *pdev, uint8_t cfgidx)	Initializes the HID interface and open the used endpoints.
static uint8_t USBD_HID_DeInit (USBD_HandleTypeDef *pdev, uint8_t cfgidx)	Un-Initializes the HID layer and close the used endpoints.
static uint8_t USBD_HID_Setup (USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req)	Handles the HID specific requests.
uint8_t USBD_HID_SendReport (USBD_HandleTypeDef *pdev, uint8_t *report, uint16_t len)	Sends HID reports.

The HID stack is initialized by calling the `USBD_HID_Init()`, Then the application has to call the `USBD_HID_SendReport()` function to send the HID reports.

The Following HID specific requests are implemented through the endpoint 0 (Control):

```
#define HID_REQ_SET_PROTOCOL           0x0B
#define HID_REQ_GET_PROTOCOL           0x03
#define HID_REQ_SET_IDLE               0x0A
#define HID_REQ_GET_IDLE               0x02
#define HID_REQ_SET_REPORT             0x09
#define HID_REQ_GET_REPORT             0x01
```

The IN endpoint address and the maximum number of bytes that can be sent are given by these defines:

```
#define HID_EPIN_ADDR                  0x81
#define HID_EPIN_SIZE                  0x04
```

6.2 Mass storage class

6.2.1 Mass storage class implementation

This module manages the MSC class V1.0 following the “Universal Serial Bus Mass Storage Class (MSC) Bulk-Only Transport (BOT) Version 1.0 Sep. 31, 1999".

This driver implements the following aspects of the specification:

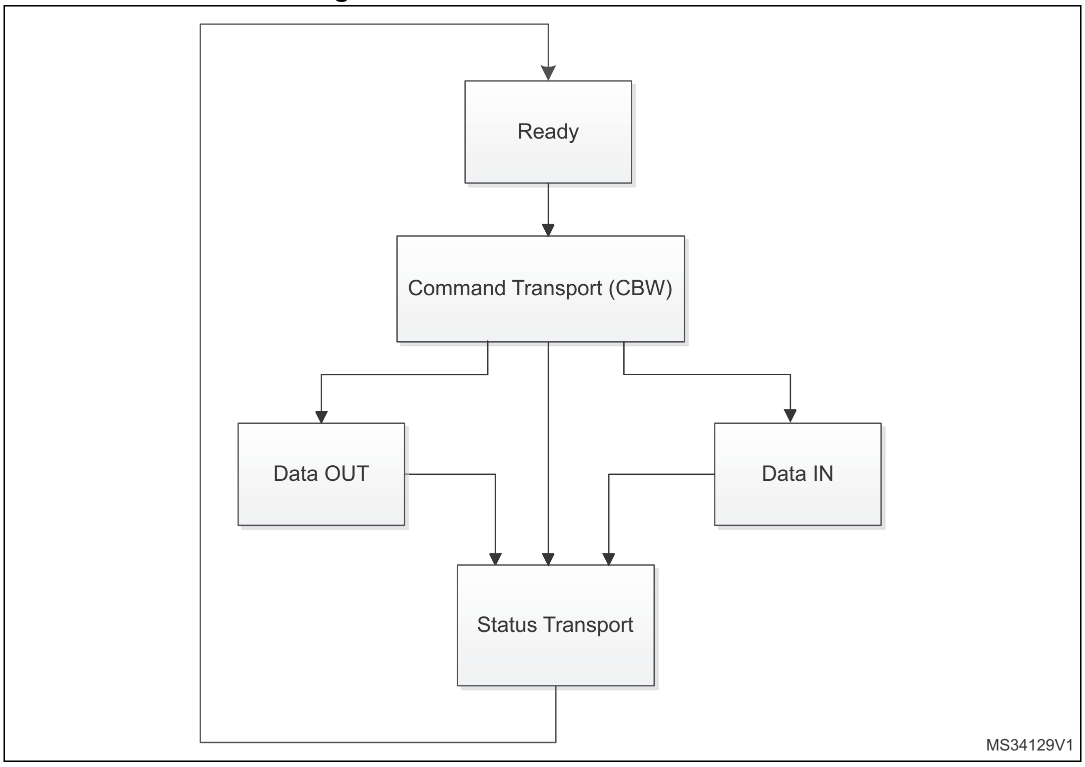
- Bulk-only transport protocol
- Subclass: SCSI transparent command set (ref. SCSI Primary Commands - 3)

The USB mass storage class is built around the Bulk Only Transfer (BOT). It uses the SCSI transparent command set.

A general BOT transaction is based on a simple basic state machine. It begins in ready state (idle state). If a CBW is received from the host, three cases can be managed:

- DATA-OUT-STAGE: when the direction flag is set to “0”, the device must be prepared to receive an amount of data indicated in cbw.dDataLength in the CBW block. At the end of data transfer, a CSW is returned with the remaining data length and the STATUS field.
- DATA-IN-STAGE: when direction flag is set to “1”, the device must be prepared to send an amount of data indicated in cbw.dDataLength in the CBW block. At the end of data transfer, a CSW is returned with the remaining data length and the STATUS field.
- ZERO DATA: in this case, no data stage is required and the CSW block is sent immediately after the CBW one.

Figure 13. BOT Protocol architecture



The following table shows the supported SCSI commands.

Table 15. SCSI commands

Command specification	Command	Remark
SCSI	SCSI_PREVENT_REMOVAL, SCSI_START_STOP_UNIT, SCSI_TEST_UNIT_READY, SCSI_INQUIRY, SCSI_READ_CAPACITY10, SCSI_READ_FORMAT_CAPACITY, SCSI_MODE_SENSE6, SCSI_MODE_SENSE10 SCSI_READ10, SCSI_WRITE10, SCSI_VERIFY10	READ_FORMAT_CAPACITY (0x23) is an UFI command.

As required by the BOT specification, the **Bulk-only mass storage reset** request (class-specific request) is implemented. This request is used to reset the mass storage device and its associated interface. This class-specific request should prepare the device for the next CBW from the host.

To generate the BOT Mass Storage Reset, the host must send a device request on the default pipe of:

- bmRequestType: Class, interface, host to device
- bRequest field set to 255 (FFh)
- wValue field set to ‘0’
- wIndex field set to the interface number
- wLength field set to ‘0’

6.2.2 Get Max MUN (class-specific request)

The device can implement several logical units that share common device characteristics. The host uses `bCBWLUN` to indicate which logical unit of the device is the destination of the CBW. The Get Max LUN device request is used to determine the number of logical units supported by the device.

To generate a Get Max LUN device request, the host sends a device request on the default pipe of:

- bmRequestType: Class, Interface, device to host
- bRequest field set to 254 (FEh)
- wValue field set to ‘0’
- wIndex field set to the interface number
- wLength field set to ‘1’

6.2.3 MSC Core files

Table 16. usbd_msc (.c,.h) files

Functions	Description
uint8_t USBD_MSC_Init (USBD_HandleTypeDef *pdev, uint8_t cfgidx)	Initializes the MSC interface and opens the used endpoints.
uint8_t USBD_MSC_DeInit (USBD_HandleTypeDef *pdev, uint8_t cfgidx)	De-initializes the MSC layer and close the used endpoints.
uint8_t USBD_MSC_Setup (USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req)	Handles the MSC specific requests.
uint8_t USBD_MSC_DataIn (USBD_HandleTypeDef *pdev, uint8_t epnum)	Handles the MSC Data In stage.
uint8_t USBD_MSC_DataOut (USBD_HandleTypeDef *pdev, uint8_t epnum)	Handles the MSC Data Out stage.

Table 17. usbd_msc_bot (.c,.h) files

Functions	Description
void MSC_BOT_Init (USBD_HandleTypeDef *pdev)	Initializes the BOT process and physical media.
void MSC_BOT_Reset (USBD_HandleTypeDef *pdev)	Resets the BOT Machine.
void MSC_BOT_DeInit (USBD_HandleTypeDef *pdev)	De-Initializes the BOT process.
void MSC_BOT_DataIn (USBD_HandleTypeDef *pdev, uint8_t epnum)	Handles the BOT data IN Stage.
void MSC_BOT_DataOut (USBD_HandleTypeDef *pdev, uint8_t epnum)	Handles the BOT data OUT Stage.
static void MSC_BOT_CBW_Decode (USBD_HandleTypeDef *pdev)	Decodes the CBW command and sets the BOT state machine accordingly.
static void MSC_BOT_SendData(USBD_HandleTypeDef *pdev, uint8_t* buf, uint16_t len)	Sends the requested data.
void MSC_BOT_SendCSW (USBD_HandleTypeDef *pdev, uint8_t CSW_Status)	Sends the Command Status Wrapper.
static void MSC_BOT_Abort (USBD_HandleTypeDef *pdev)	Aborts the current transfer.
void MSC_BOT_CplClrFeature (USBD_HandleTypeDef *pdev, uint8_t epnum)	Completes the Clear Feature request.

Table 18. usbd_msc_scsi (.c,.h)

Functions	Description
int8_t SCSI_ProcessCmd(USBD_HandleTypeDef *pdev, uint8_t lun, uint8_t *params)	Processes the SCSI commands.
static int8_t SCSI_TestUnitReady(USBD_HandleTypeDef *pdev, uint8_t lun, uint8_t *params)	Processes the SCSI Test Unit Ready command.
static int8_t SCSI_Inquiry(USBD_HandleTypeDef *pdev, uint8_t lun, uint8_t *params)	Processes the Inquiry command.
static int8_t SCSI_ReadCapacity10(USBD_HandleTypeDef *pdev, uint8_t lun, uint8_t *params)	Processes the Read Capacity 10 command.
static int8_t SCSI_ReadFormatCapacity(USBD_HandleTypeDef *pdev, uint8_t lun, uint8_t *params)	Processes the Read Format Capacity command.
static int8_t SCSI_ModeSense6 (USBD_HandleTypeDef *pdev, uint8_t lun, uint8_t *params)	Processes the Mode Sense 6 command.
static int8_t SCSI_ModeSense10 (USBD_HandleTypeDef *pdev, uint8_t lun, uint8_t *params)	Processes the Mode Sense 10 command.
static int8_t SCSI_RequestSense (USBD_HandleTypeDef *pdev, uint8_t lun, uint8_t *params)	Processes the Request Sense command.
void SCSI_SenseCode (USBD_HandleTypeDef *pdev, uint8_t lun, uint8_t sKey, uint8_t ASC)	Loads the last error code in the error list.
static int8_t SCSI_StartStopUnit (USBD_HandleTypeDef *pdev, uint8_t lun, uint8_t *params)	Processes the Start Stop Unit command.
static int8_t SCSI_Read10 (USBD_HandleTypeDef *pdev, uint8_t lun , uint8_t *params)	Processes the Read10 command.
static int8_t SCSI_Write10 (USBD_HandleTypeDef *pdev, uint8_t lun , uint8_t *params)	Processes the Write10 command.
static int8_t SCSI_Verify10 (USBD_HandleTypeDef *pdev, uint8_t lun , uint8_t *params)	Processes the Verify10 command.
static int8_t SCSI_CheckAddressRange (USBD_HandleTypeDef *pdev, uint8_t lun , uint32_t blk_offset , uint16_t blk_nbr)	Checks if the LBA is inside the address range.
static int8_t SCSI_ProcessRead (USBD_HandleTypeDef *pdev, uint8_t lun)	Handles the Burst Read process.
static int8_t SCSI_ProcessWrite (USBD_HandleTypeDef *pdev, uint8_t lun)	Handles the Burst Write process.

6.2.4 Disk operation structure definition

Figure 14. Disk operation structure description

```
 USBD_StorageTypeDef USBD_DISK_fops = {
  STORAGE_Init,
  STORAGE_GetCapacity,
  STORAGE_IsReady,
  STORAGE_IsWriteProtected,
  STORAGE_Read,
  STORAGE_Write,
  STORAGE_GetMaxLun,
  STORAGE_Inquirydata,
};
```

Note: MicroSD is the default media interface provided by the library. However you can add other media (Flash memory....) using the template file provided in usbd_msc_storage_template.c

The storage callback for MSC class is added in the user application by calling USBD_MSC_RegisterStorage(&USBD_Device, &USBD_DISK_fops).

The standard inquiry data are given by the user inside the STORAGE_Inquiry data array. They should be defined as shown in *Figure 15*.

Figure 15. Example of standard inquiry definition

```
int8_t STORAGE_Inquirydata[] = { /* 36 */
  /* LUN 0 */
  0x00,
  0x80,
  0x02,
  0x02,
  (STANDARD_INQUIRY_DATA_LEN - 5),
  0x00,
  0x00,
  0x00,
  'S', 'T', 'M', ' ', ' ', ' ', ' ', ' ', /* Manufacturer: 8 bytes  */
  'P', 'r', 'o', 'd', 'u', 'c', 't', ' ', /* Product     : 16 Bytes */
  ' ', ' ', ' ', ' ', ' ', ' ', ' ', ' ',
  '0', '.', '0','1',                      /* Version     : 4 Bytes  */
};
```

6.2.5 Disk operation functions

Table 19. Disk operation functions

Functions	Description
int8_t STORAGE_Init (uint8_t lun)	Initializes the storage medium.
int8_t STORAGE_GetCapacity (uint8_t lun, uint32_t *block_num, uint16_t *block_size)	Returns the medium capacity and block size.
int8_t STORAGE_IsReady (uint8_t lun)	Checks whether the medium is ready.
int8_t STORAGE_IsWriteProtected (uint8_t lun)	Checks whether the medium is write-protected.
int8_t STORAGE_Read (uint8_t lun, uint8_t *buf, uint32_t blk_addr, uint16_t blk_len)	Reads data from the medium: blk_address is given in sector unit blk_len is the number of the sector to be processed.
int8_t STORAGE_Write (uint8_t lun, uint8_t *buf, uint32_t blk_addr, uint16_t blk_len)	Writes data to the medium: blk_address is given in sector unit blk_len is the number of the sector to be processed.
int8_t STORAGE_GetMaxLun (void)	Returns the number of supported logical units.

6.3 Device firmware upgrade (DFU) class

The DFU core manages the DFU class V1.1 following the "Device Class Specification for Device Firmware Upgrade Version 1.1 Aug 5, 2004".

This core implements the following aspects of the specification:

- Device descriptor management
- Configuration descriptor management
- Enumeration as DFU device (in DFU mode only)
- Request management (supporting ST DFU sub-protocol)
- Memory request management (Download / Upload / Erase / Detach / GetState / GetStatus)
- DFU state machine implementation.

Note: ST DFU sub-protocol is compliant with DFU protocol. It uses sub-requests to manage memory addressing, command processing, specific memory operations (that is, memory erase, etc.)

As required by the DFU specification, only endpoint 0 is used in this application.

Other endpoints and functions may be added to the application (that is, HID, etc.).

These aspects may be enriched or modified for a specific user application.

The USB driver does not implement the Manifestation Tolerant mode defined in the specification. However it is possible to manage this feature by modifying the driver.

6.3.1 Device firmware upgrade (DFU) class implementation

The DFU transactions are based on endpoint 0 (control endpoint) transfer. All requests and status control are sent / received through this endpoint.

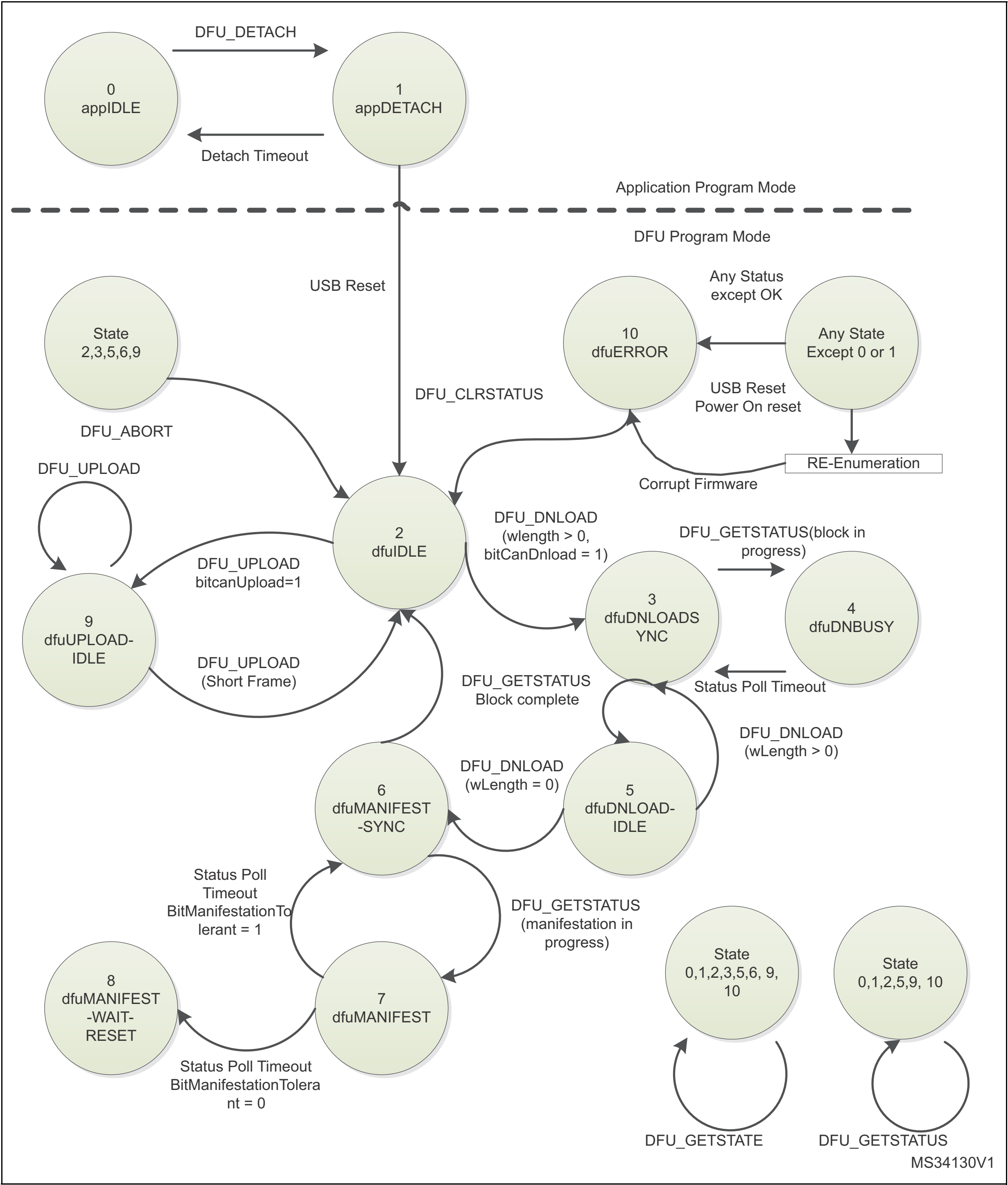
The DFU state machine is based on the following states:

Table 20. DFU states

State	State code
appIDLE	0x00
appDETACH	0x01
dfuIDLE	0x02
dfuDNLOAD-SYNC	0x03
dfuDNBUSY	0x04
dfuDNLOAD-IDLE	0x05
dfuMANIFEST-SYNC	0x06
dfuMANIFEST	0x07
dfuMANIFEST-WAIT-RESET	0x08
dfuUPLOAD-IDLE	0x09
dfuERROR	0x0A

The allowed state transitions are described in the specification document.

Figure 16. DFU Interface state transitions diagram



To protect the application from spurious accesses before initialization, the initial state of the DFU core (after startup) is dfuERROR. The host must then clear this state by sending a DFU_CLRSTATE request before generating another request.

The DFU core manages all supported requests (see *Table 21*).

Table 21. Supported requests

Request	Code	Details
DFU_DETACH	0x00	When bit 3 in *bmAttributes* (bit *WillDetach*) is set, the device generates a detach-attach sequence on the bus when it receives this request.
DFU_DNLOAD	0x01	The firmware image is downloaded via the control-write transfers initiated by the *DFU_DNLOAD* class specific request.
DFU_UPLOAD	0x02	The purpose of the upload is to provide the capability of retrieving and archiving a device firmware.
DFU_GETSTATUS	0x03	The host employs the *DFU_GETSTATUS* request to facilitate synchronization with the device.
DFU_CLRSTATUS	0x04	Upon receipt of *DFU_CLRSTATUS*, the device sets a status of OK and transitions to the *dfuIDLE* state.
DFU_GETSTATE	0x05	This request solicits a report about the state of the device.
DFU_ABORT	0x06	The *DFU_ABORT* request enables the host to exit from certain states and to return to the *DFU_IDLE* state.

Each transfer to the control endpoint belong to one of the two main categories:

- Data transfers: These transfers are used to
  - Get some data from the device (DFU_GETSTATUS, DFU_GETSTATE and DFU_UPLOAD).
  - Or, to send data to the device (DFU_DNLOAD).
- No-Data transfers: These transfers are used to send control requests from host to device (DFU_CLRSTATUS, DFU_ABORT and DFU_DETACH).

6.3.2 Device firmware upgrade (DFU) Class core files

usbd_dfu (.c, .h)

This driver is the main DFU core. It allows the management of all DFU requests and state machine. It does not directly deal with memory media (managed by lower layer drivers).

Table 22. usbd_dfu (.c,.h) files

Functions	Description
static uint8_t USBD_DFU_Init (USBD_HandleTypeDef *pdev, uint8_t cfgidx);	Initializes the DFU interface.
static uint8_t USBD_DFU_DeInit (USBD_HandleTypeDef *pdev, uint8_t cfgidx);	De-initializes the DFU layer.
static uint8_t USBD_DFU_Setup (USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req);	Handles the DFU request parsing.
static uint8_t USBD_DFU_EP0_TxReady (USBD_HandleTypeDef *pdev);	Handles the DFU control endpoint data IN stage.
static uint8_t USBD_DFU_EP0_RxReady (USBD_HandleTypeDef *pdev);	Handles the DFU control endpoint data OUT stage.

Table 22. usbd_dfu (.c,.h) files (continued)

Functions	Description
static uint8_t* USBD_DFU_GetUsrStringDesc (USBD_HandleTypeDef *pdev, uint8_t index , uint16_t *length);	Manages the transfer of memory interfaces string descriptors.
static void DFU_Detach (USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req);	Handles the DFU DETACH request.
static void DFU_Download (USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req);	Handles the DFU DNLOAD request.
static void DFU_Upload (USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req);	Handles the DFU UPLOAD request.
static void DFU_GetStatus (USBD_HandleTypeDef *pdev);	Handles the DFU GETSTATUS request.
static void DFU_ClearStatus (USBD_HandleTypeDef *pdev);	Handles the DFU CLRSTATUS request.
static void DFU_GetState (USBD_HandleTypeDef *pdev);	Handles the DFU GETSTATE request.
static void DFU_Abort (USBD_HandleTypeDef *pdev);	Handles the DFU ABORT request.
static void DFU_Leave (USBD_HandleTypeDef *pdev);	Handles the sub-protocol DFU leave DFU mode request (leaves DFU mode and resets device to jump to user loaded code).

Note: Internal Flash memory is the default memory provided by the library. However you can add other memories using the `usbd_dfu_media_template.c` *template file.*

To use the driver:

1. Use the file `usbd_conf.h`, to configure:
   – The number of media (memories) to be supported (define USBD_DFU_MAX_ITF_NUM).
   – The application default address (where the image code should be loaded): define USBD_DFU_APP_DEFAULT_ADD.
2. Call USBD_DFU_Init() function to initialize all memory interfaces and DFU state machine.
3. All control/request operations are performed through control endpoint 0, through the functions: USBD_DFU_Setup() and USBD_DFU_EP0_TxReady(). These functions can be used to call each memory interface callback (read/write/erase/get state...) depending on the generated DFU requests. No user action is required for these operations.
4. To close the communication, call the USBD_DFU_DeInit() function.

Note: When the DFU application starts, the default DFU state is `DFU_STATE_ERROR`*. This state is set to protect the application from spurious operations before having a correct configuration*

6.4 Audio class

The USB driver manages the Audio Class 1.0 following the “USB Device Class Definition for Audio Devices V1.0 Mar 18, 98".

The driver implements the following aspects of the specification:

- Device descriptor management
- Configuration descriptor management
- Standard AC Interface Descriptor management
- 1 Audio Streaming Interface (with single channel, PCM, Stereo mode)
- 1 Audio Streaming endpoint
- 1 Audio Terminal Input (1 channel)
- Audio Class-Specific AC Interfaces
- Audio Class-Specific AS Interfaces
- Audio Control Requests: only `SET_CUR` and `GET_CUR` requests are supported (for Mute)
- Audio Feature Unit (limited to Mute control)
- Audio Synchronization type: Asynchronous
- Single fixed audio sampling rate (configurable in *usbd_conf.h* file)

Note: The Audio Class 1.0 is based on USB Specification 1.0 and thus supports only Low and Full speed modes and does not allow High Speed transfers. Please refer to “USB Device Class Definition for Audio Devices V1.0 Mar 18, 98" for more details.

These aspects can be enriched or modified for a specific user application.

This driver does not implement the following aspects of the specification (but it is possible to manage these features with some modifications on this driver):

- Audio Control endpoint management
- Audio Control requests other than `SET_CUR` and `GET_CUR`
- Abstraction layer for Audio Control requests (only mute functionality is managed)
- Audio Synchronization type: Adaptive
- Audio Compression modules and interfaces
- MIDI interfaces and modules
- Mixer/Selector/Processing/Extension Units (featured unit is limited to Mute control)
- Any other application-specific modules
- Multiple and Variable audio sampling rates
- Audio Out Streaming Endpoint/Interface (microphone)

6.4.1 Audio class implementation

The Audio transfers are based on isochronous endpoint transactions. Audio control requests are also managed through control endpoint (endpoint 0).

In each frame, an audio data packet is transferred and must be consumed during this frame (before the next frame). The audio quality depends on the synchronization between data transfer and data consumption. This driver implements simple mechanism of synchronization relying on accuracy of the delivered I2S clock. At each start of frame, the driver checks if the consumption of the previous packet has been correctly performed and aborts it if it is still ongoing. To prevent any data overwrite, two main protections are used:

- Using DMA for data transfer between USB buffer and output device registers (I2S).
- Using multi-buffers to store data received from USB.

Based on this mechanism, if the clock accuracy or the consumption rates are not high enough, it will result in a bad audio quality.

This mechanism may be enhanced by implementing more flexible audio flow controls like USB feedback mode, dynamic audio clock correction or audio clock generation/control using SOF event.

The driver also supports basic Audio Control requests. To keep the driver simple, only two requests have been implemented. However, other requests can be supported by slightly modifying the audio core driver.

Table 23. Audio control requests

Request	Supported	Meaning
SET_CUR	Yes	Sets Mute mode On or Off (can also be updated to set volume level…).
SET_MIN	No	NA.
SET_MAX	No	NA.
SET_RES	No	NA.
SET_MEM	No	NA.
GET_CUR	Yes	Gets Mute mode state (can also be updated to get volume level…).
GET_MIN	No	NA.
GET_MAX	No	NA.
GET_RES	No	NA.
GET_MEM	No	NA.

6.4.2 Audio core files

usbd_audio (.c, .h)

This driver is the audio core. It manages audio data transfers and control requests. It does not directly deal with audio hardware (which is managed by lower layer drivers).

Table 24. usbd_audio_core (.c,.h) files

Functions	Description
static uint8_t USBD_AUDIO_Init (USBD_HandleTypeDef *pdev, uint8_t cfgidx);	Initializes the Audio interface.
static uint8_t USBD_AUDIO_DeInit (USBD_HandleTypeDef *pdev, uint8_t cfgidx);	De-initializes the Audio interface.
static uint8_t USBD_AUDIO_Setup (USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req);	Handles the Audio control request parsing.

Table 24. usbd_audio_core (.c,.h) files (continued)

Functions	Description
static uint8_t USBD_AUDIO_EP0_RxReady (USBD_HandleTypeDef *pdev);	Handles audio control requests data.
static uint8_t USBD_AUDIO_DataIn (USBD_HandleTypeDef *pdev, uint8_t epnum);	Handles the Audio In data stage.
static uint8_t USBD_AUDIO_DataOut (USBD_HandleTypeDef *pdev, uint8_t epnum);	Handles the Audio Out data stage.
static uint8_t USBD_AUDIO_SOF (USBD_HandleTypeDef *pdev);	Handles the SOF event (data buffer update and synchronization).
static void AUDIO_REQ_GetCurrent(USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req);	Handles the GET_CUR Audio control request.
static void AUDIO_REQ_SetCurrent(USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req);	Handles the SET_CUR Audio control request.

The low layer hardware interfaces are managed through their respective driver structure:

Figure 17. Audio core structures

```
typedef struct
{
    int8_t  (*Init)         (uint32_t  AudioFreq, uint32_t Volume,
uint32_t options);
    int8_t  (*DeInit)       (uint32_t options);
    int8_t  (*AudioCmd)     (uint8_t* pbuf, uint32_t size, uint8_t
cmd);
    int8_t  (*VolumeCtl)    (uint8_t vol);
    int8_t  (*MuteCtl)      (uint8_t cmd);
    int8_t  (*PeriodicTC)   (uint8_t cmd);
    int8_t  (*GetState)     (void);
}USBD_AUDIO_ItfTypeDef;
```

Each audio hardware interface driver should provide a structure pointer of type USBD_AUDIO_ItfTypeDef. The functions and constants pointed by this structure are listed in the following sections. If a functionality is not supported by a given memory interface, the relative field is set as NULL value.

usbd_audio_if (.c, .h)

This driver manages the low layer audio hardware. *usbd_audio_if.c/.h* driver manages the Audio Out interface (from USB to audio speaker/headphone). user can call lower layer Codec driver (i.e. stm324xg_eval_audio.*c/.h*) for basic audio operations (play/pause/volume control...).

This driver provides the structure pointer:

extern USBD_AUDIO_ItfTypeDef USBD_AUDIO_fops;

Table 25. usbd_audio_if (.c,.h) files

Functions	Description
static int8_t Audio_Init(uint32_t AudioFreq, uint32_t Volume, uint32_t options);	Initializes the audio interface.
static int8_t Audio_DeInit(uint32_t options);	De-initializes the audio interface and free used resources.
static int8_t Audio_PlaybackCmd(uint8_t* pbuf, uint32_t size, uint8_t cmd);	Handles audio player commands (play, pause…).
static int8_t Audio_VolumeCtl(uint8_t vol);	Handles audio player volume control.
static int8_t Audio_MuteCtl(uint8_t cmd);	Handles audio player mute state.
static int8_t Audio_PeriodicTC(uint8_t cmd);	Handles the end of current packet transfer (not needed for the current version of the driver).
static int8_t Audio_GetState(void);	Returns the current state of the driver audio player (Playing/Paused/Error …).

Note: The usbd_audio_if_template (.c,.h) file provides a template driver which allows you to implement additional functions for your Audio application

The Audio player state is managed through the following states:

Table 26. Audio player states

State	Code	Description
AUDIO_CMD_START	0x01	Audio player is initialized and ready.
AUDIO_CMD_PLAY	0x02	Audio player is currently playing.
AUDIO_CMD_STOP	0x04	Audio player is stopped.

6.4.3 How to use this driver

This driver uses an abstraction layer for hardware driver (i.e. HW Codec, I2S interface, I2C control interface...). This abstraction is performed through a lower layer (i.e. *usbd_audio_if.c*) which you can modify depending on the hardware available for your application.

To use this driver:

1. Configure the audio sampling rate (define USBD_AUDIO_FREQ) through the file *usbd_conf.h*,
2. Call the USBD_AUDIO_Init() function at startup to configure all necessary firmware and hardware components (application-specific hardware configuration functions are also called by this function). The hardware components are managed by a lower layer interface (i.e. *usbd_audio_if.c*) and can be modified by user depending on the application needs.
3. The entire transfer is managed by the following functions (no need for user to call any function for out transfers):
   – usbd_audio_DataIn() and usbd_audio_DataOut() which update the audio buffers with the received or transmitted data. For Out transfers, when data are received,

they are directly copied into the audiobuffer and the write buffer (wr_ptr) is incremented.

4. The Audio Control requests are managed by the functions USBD_AUDIO_Setup() and USBD_AUDIO_EP0_RxReady(). These functions route the Audio Control requests to the lower layer (i.e. *usbd_audio_if.c*). In the current version, only SET_CUR and GET_CUR requests are managed and are used for mute control only.

6.4.4 Audio known limitations

- If a low audio sampling rate is configured (define USBD_AUDIO_FREQ below 24 kHz) it may result in noise issue at pause/resume/stop operations. This is due to software timing tuning between stopping I2S clock and sending mute command to the external Codec.
- Supported audio sampling rates range from 96 kHz to 24 kHz (non-multiple of 1 kHz values like 11.025 kHz, 22.05 kHz or 44.1 kHz are not supported by this driver). For frequencies multiple of 1000 Hz, the Host will send integer number of bytes each frame (1 ms). When the frequency is not multiple of 1000Hz, the Host should send non integer number of bytes per frame. This is in fact managed by sending frames with different sizes (i.e. for 22.05 kHz, the Host will send 19 frames of 22 bytes and one frame of 23 bytes). This difference of sizes is not managed by the Audio core and the extra byte will always be ignored. It is advised to set a high and standard sampling rate in order to get best audio quality (i.e. 96 kHz or 48 kHz). Note that maximum allowed audio frequency is 96 kHz (this limitation is due to the Codec used on the Evaluation board. The STM32 I2S cell enables reaching 192 kHz).

6.5 Communication device class (CDC)

The USB driver manages the “Universal Serial Bus Class Definitions for Communications Devices Revision 1.2 November 16, 2007" and the sub-protocol specification of “Universal Serial Bus Communications Class Subclass Specification for PSTN Devices Revision 1.2 February 9, 2007".

This driver implements the following aspects of the specification:

- Device descriptor management
- Configuration descriptor management
- Enumeration as CDC device with 2 data endpoints (IN and OUT) and 1 command endpoint (IN)
- Request management (as described in section 6.2 in specification)
- Abstract Control Model compliant
- Union Functional collection (using 1 IN endpoint for control)
- Data interface class

Note: *For the Abstract Control Model, this core can only transmit the requests to the lower layer dispatcher (i.e.* usbd_cdc_vcp.c/.h*) which should manage each request and perform relative actions.*

These aspects can be enriched or modified for a specific user application.

This driver does not implement the following aspects of the specification (but it is possible to manage these features with some modifications on this driver):

- Any class-specific aspect relative to communication classes should be managed by user application.
- All communication classes other than PSTN are not managed.

6.5.1 Communication

The CDC core uses two endpoint/transfer types:

- Bulk endpoints for data transfers (1 OUT endpoint and 1 IN endpoint)
- Interrupt endpoints for communication control (CDC requests; 1 IN endpoint)

Data transfers are managed differently for IN and OUT transfers:

6.5.2 Data IN transfer management (from device to host)

The data transfer is managed periodically depending on host request (the device specifies the interval between packet requests). For this reason, a circular static buffer is used for storing data sent by the device terminal (i.e. USART in the case of Virtual COM Port terminal).

6.5.3 Data OUT transfer management (from host to device)

In general, the USB is much faster than the output terminal (i.e. the USART maximum bitrate is 115.2 Kbps while USB bitrate is 12 Mbps for Full speed mode and 480 Mbps in High speed mode). Consequently, before sending new packets, the host has to wait until the device has finished to process the data sent by host. Thus, there is no need for circular data buffer when a packet is received from host: the driver calls the lower layer OUT transfer function and waits until this function is completed before allowing new transfers on the OUT endpoint (meanwhile, OUT packets will be NACKed).

6.5.4 Command request management

In this driver, control endpoint (endpoint 0) is used to manage control requests. But a data interrupt endpoint may be used also for command management. If the request data size does not exceed 64 bytes, the endpoint 0 is sufficient to manage these requests.

The CDC driver does not manage command requests parsing. Instead, it calls the lower layer driver control management function with the request code, length and data buffer. Then this function should parse the requests and perform the required actions.

6.5.5 Command device class (CDC) core files

usbd_cdc (.c, .h)

This driver is the CDC core. It manages CDC data transfers and control requests. It does not directly deal with CDC hardware (which is managed by lower layer drivers).

Table 27. usbd_cdc (.c,.h) files

Functions	Description
static uint8_t USBD_CDC_Init (USBD_HandleTypeDef *pdev, uint8_t cfgidx);	Initializes the CDC interface.
static uint8_t USBD_CDC_DeInit (USBD_HandleTypeDef *pdev, uint8_t cfgidx);	De-initializes the CDC interface.
static uint8_t USBD_CDC_Setup (USBD_HandleTypeDef *pdev, USBD_SetupReqTypedef *req);	Handles the CDC control requests.
static uint8_t USBD_CDC_EP0_RxReady (USBD_HandleTypeDef *pdev);	Handles CDC control request data.
static uint8_t USBD_CDC_DataIn (USBD_HandleTypeDef *pdev, uint8_t epnum);	Handles the CDC IN data stage.
static uint8_t USBD_CDC_DataOut (USBD_HandleTypeDef *pdev, uint8_t epnum);	Handles the CDC Out data stage.
uint8_t USBD_CDC_RegisterInterface (USBD_HandleTypeDef *pdev, USBD_CDC_ItfTypeDef *fops)	Adds CDC Interface Class.
uint8_t USBD_CDC_SetTxBuffer (USBD_HandleTypeDef *pdev, uint8_t *pbuff, uint16_t length)	Sets application TX Buffer.
uint8_t USBD_CDC_SetRxBuffer (USBD_HandleTypeDef *pdev, uint8_t *pbuff)	Sets application RX Buffer.
uint8_t USBD_CDC_TransmitPacket(USBD_HandleTypeDef *pdev)	Transmits Transfer completed callback.
uint8_t USBD_CDC_ReceivePacket(USBD_HandleTypeDef *pdev)	Receives Transfer completed callback.

The low layer hardware interfaces are managed through their respective driver structure

Figure 18. CDC core structures

```
typedef struct _USBD_CDC_Itf
{
  int8_t (* Init)          (void);
  int8_t (* DeInit)        (void);
  int8_t (* Control)       (uint8_t, uint8_t * , uint16_t);
  int8_t (* Receive)       (uint8_t *, uint32_t *);

}USBD_CDC_ItfTypeDef;
```

Each hardware interface driver should provide a structure pointer of type USBD_CDC_ItfTypeDef. The functions pointed by this structure are listed in the following sections.

If a function is not supported by a given memory interface, the relative field is set as NULL value.

Note: *In order to get the best performance, it is advised to calculate the values needed for the following parameters (all of them are configurable through defines in the* usbd_cdc.h and *usbd_cdc_interface.h files):*

Table 28. Configurable CDC parameters

Define	**Parameter**	**Typical value**	
		Full Speed	**High Speed**
CDC_DATA_HS_IN_PACKET_SIZE /CDC_DATA_FS_IN_PACKET_SIZE	Size of each IN data packet.	64	512
CDC_DATA_HS_OUT_PACKET_SIZE/CDC_DATA_FS_OUT_PACKET_SIZE	Size of each OUT data packet.	64	512
APP_TX_DATA_SIZE	Total size of circular temporary buffer for OUT data transfer.	2048	2048
APP_RX_DATA_SIZE	Total size of circular temporary buffer for IN data transfer.	2048	2048

usbd_cdc_interface (.c, .h)

This driver can be part of the user application. It is not provided in the library, but a template **usbd_cdc_if_template *(.c, .h)*** can be used to build it and an example is provided for the USART interface. It manages the low layer CDC hardware. The *usbd_cdc_interface.c/.h* driver manages the terminal interface configuration and communication (i.e. USART interface configuration and data send/receive).

This driver provides the structure pointer:

Figure 19. CDC interface callback structure

```
USBD_CDC_ItfTypeDef USBD_CDC_fops =
{
  CDC_Itf_Init,
  CDC_Itf_DeInit,
  CDC_Itf_Control,
  CDC_Itf_Receive
};
```

Table 29. usbd_cdc_interface (.c,.h) files

Functions	**Description**
static int8_t CDC_Itf_Init (void);	Initializes the low layer CDC interface.
static int8_t CDC_Itf_DeInit (void);	De-initializes the low layer CDC interface.

Table 29. usbd_cdc_interface (.c,.h) files

Functions	Description
static int8_t CDC_Itf_Control (uint8_t cmd, uint8_t* pbuf, uint16_t length);	Handles CDC control request parsing and execution.
static int8_t CDC_Itf_Receive (uint8_t* pbuf, uint32_t *Len);	Handles CDC data reception from USB host to low layer terminal (OUT transfers).

In order to accelerate data management for IN/OUT transfers, the low layer driver (*usbd_cdc_interface.c/.h*) use these global variables:

Table 30. Variables used by usbd_cdc_xxx_if.c/.h

Variable	Usage
uint8_t UserRxBuffer[APP_RX_DATA_SIZE]	Writes CDC received data in this buffer from USART. These data will be sent over USB IN endpoint in the CDC core functions.
uint32_t UserTxBufPtrOut	Increments this pointer or rolls it back to start the address when writing received data in the buffer UserRxBuffer.
uint8_t UserTxBuffer[APP_TX_DATA_SIZE]	Writes CDC received data in this buffer. These data are received from USB OUT endpoint in the CDC core functions.
UserTxBufPtrIn	Increments this pointer or rolls back to start address when data are received over USART.

6.5.6 How to use

The USB driver uses an abstraction layer for hardware driver (i.e. USART control interface...). This abstraction is performed through a lower layer (i.e. stm32fxxx_hal_msp.*c*) which you can modify depending on the hardware available for your application.

To use this driver:

1. Through the file *usbd_cdc.h* and *usbd_cdc_interface.h,* configure:
   – The Data IN and OUT and command packet sizes (defines CDC_DATA_XX_IN_PACKET_SIZE, CDC_DATA_XX_OUT_PACKET_SIZE)
   – The size of the temporary circular buffer for IN/OUT data transfer (define APP_RX_DATA_SIZE and APP_TX_DATA_SIZE).
   – The device string descriptors.
2. Call the function USBD_CDC_Init() at startup to configure all necessary firmware and hardware components (application-specific hardware configuration functions are called by this function as well). The hardware components are managed by a lower layer

interface (i.e. *usbd_cdc_interface.c*) and can be modified by user depending on the application needs.

3. CDC IN and OUT data transfers are managed by two functions:
   - USBD_CDC_SetTxBuffer should be called by user application each time a data (or a certain number of data) is available to be sent to the USB Host from the hardware terminal.
   - USBD_CDC_SetRxBuffer is called by the CDC core each time a buffer is sent from the USB Host and should be transmitted to the hardware terminal. This function should exit only when all data in the buffer are sent (the CDC core then blocks all coming OUT packets until this function finishes processing the previous packet).
4. CDC control requests should be handled by the function Controllability(). This function is called each time a request is received from Host and all its relative data are available if any. This function should parse the request and perform the needed actions.
5. To close the communication, call the function USBD_CDC_DeInit(). This closes the used endpoints and calls lower layer de-initialization functions.

6.5.7 CDC known limitations

When using this driver with the OTG HS core, enabling DMA mode (define USB_OTG_HS_INTERNAL_DMA_ENABLED in *usb_conf.h* file) results in data being sent only by multiple of 4 bytes. This is due to the fact that USB DMA does not allow sending data from non word-aligned addresses. For this specific application, it is advised not to enable this option unless required.

6.6 Adding a custom class

This section explains how to create a new custom class based on an existing USB class.

To create a new custom Class, follow the steps below:

1. Add USBD_CustomClass_cb (In order to receive various USB bus Events) as described in *Section 5.3*, in the **usbd_template.c/.h available under Class/Template**

directory. This template contains all the functions that should be adapted to the application's needs and may be also used to implement any type of USB Device class.

2. Customizing the descriptors:

   The descriptors retrieved by the host must be configured to describe a device depending on the specifications for the application class devices. The following list is not complete but gives an overview about the various descriptors that may be required:
   - Standard device descriptor
   - Standard configuration descriptor
   - Standard interface descriptor for the Class that is implemented
   - Standard endpoint descriptors for IN and OUT endpoints
3. The firmware must configure the STM32 to enable USB transfer (isochronous, Bulk, Interrupt or Control) depending on the user application:
   - In the DataIn and DataOut functions, the user can implement the internal protocol or state machine
   - In the *Setup*; the class specific requests are to be implemented. The configuration descriptor is to be added as an array and passed to the USB device library.
   - Through the GetConfigDescriptor function which should return a pointer to the USB configuration descriptor and its length.
   - Additional functions could be added as the IsoINIncomplete and IsoOUTIncomplete could be eventually used to handle incomplete isochronous transfers (for more information, refer to the *USB audio device example*).
   - EP0_TxSent and EP0_RxReady could be eventually used when the application needs to handle events occurring before the Zero Length Packets (see the *DFU example*).
4. Memory allocation process: Memory is allocated to the applications using the malloc (USBD_malloc):
   - USBD_malloc(sizeof (USBD_**CUSTOM_CLASS**_HandleTypeDef)): this is dynamically allocates memory for a Class structure

6.7 Library footprint optimization

In this section we review some basic tips about how to optimize the footprint of an application developed on top of the USB device library.

Reducing the USB examples footprint is important objective especially for STM32 products with small Flash/RAM memory size, such as STM32L0 and F0 Series.

Reduce the heap and stack size settings (in the Linker file)

The stack is the memory area where the program stores:

- Local variables
- Return addresses
- Function arguments
- Compiler temporaries
- Interrupt contexts

If your linker configuration reserves more amounts of heap and stack than necessary for your application, you can determine accurately the appropriate sizes.

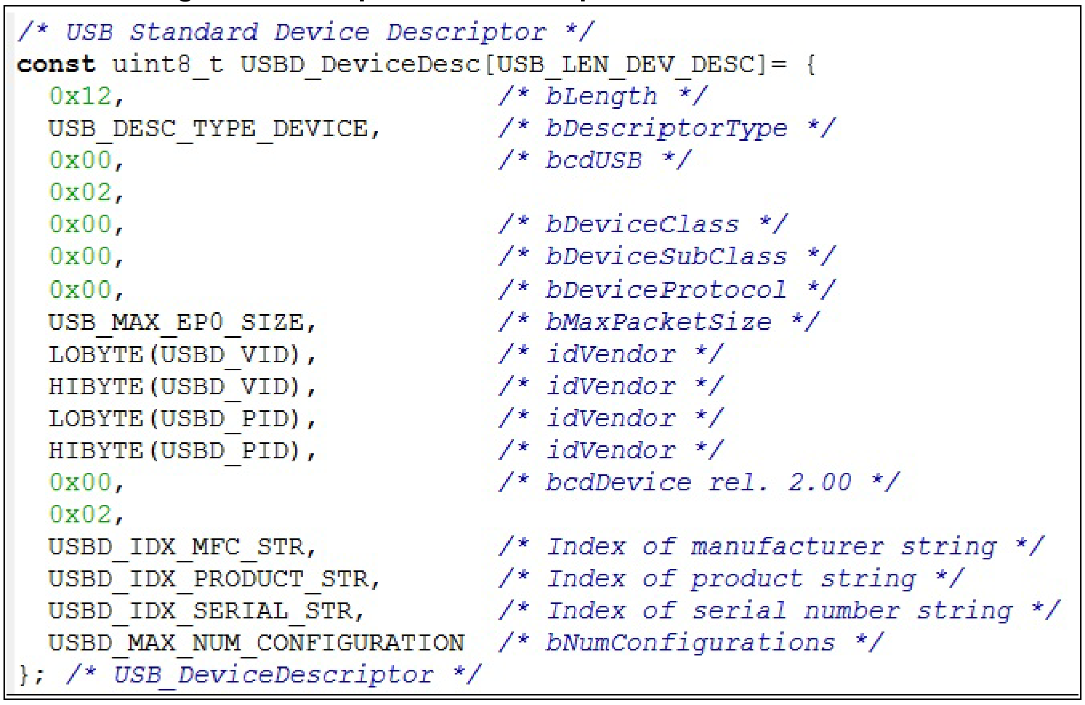
Whenever possible use local instead if global variables

If a variable is used only in a function, then it should be declared inside the function as a local variable.

Constant should be allocated in the flash

It is recommended to allocate all constant global variables, which never change, to a read-only section. As example, the USB descriptors are declared as constant using the C keyword "const".

Figure 20. Example of USB descriptors declared as constants



```
/* USB Standard Device Descriptor */
const uint8_t USBD_DeviceDesc[USB_LEN_DEV_DESC]= {
  0x12,                       /* bLength */
  USB_DESC_TYPE_DEVICE,       /* bDescriptorType */
  0x00,                       /* bcdUSB */
  0x02,
  0x00,                       /* bDeviceClass */
  0x00,                       /* bDeviceSubClass */
  0x00,                       /* bDeviceProtocol */
  USB_MAX_EP0_SIZE,           /* bMaxPacketSize */
  LOBYTE(USBD_VID),           /* idVendor */
  HIBYTE(USBD_VID),           /* idVendor */
  LOBYTE(USBD_PID),           /* idVendor */
  HIBYTE(USBD_PID),           /* idVendor */
  0x00,                       /* bcdDevice rel. 2.00 */
  0x02,
  USBD_IDX_MFC_STR,           /* Index of manufacturer string */
  USBD_IDX_PRODUCT_STR,       /* Index of product string */
  USBD_IDX_SERIAL_STR,        /* Index of serial number string */
  USBD_MAX_NUM_CONFIGURATION  /* bNumConfigurations */
}; /* USB_DeviceDescriptor */
```

Use static memory allocation rather than malloc

The USB device library uses dynamic memory allocation for a class handle structure to allow multi-instance support (in case of the dual core operation), this means for example we can have same USB class used for the two instances of the USB (HS and FS).

The secondary reason for using dynamic allocation is to allow freeing memory when USB is no more used.

However dynamic memory allocation adds some footprint overhead, mainly for the ROM memory. For this it's advised to use static allocation for the low memory STM32 devices or when multi-instance support is not needed. In that case it's necessary to declare a static buffer having the size of the class handle structure.

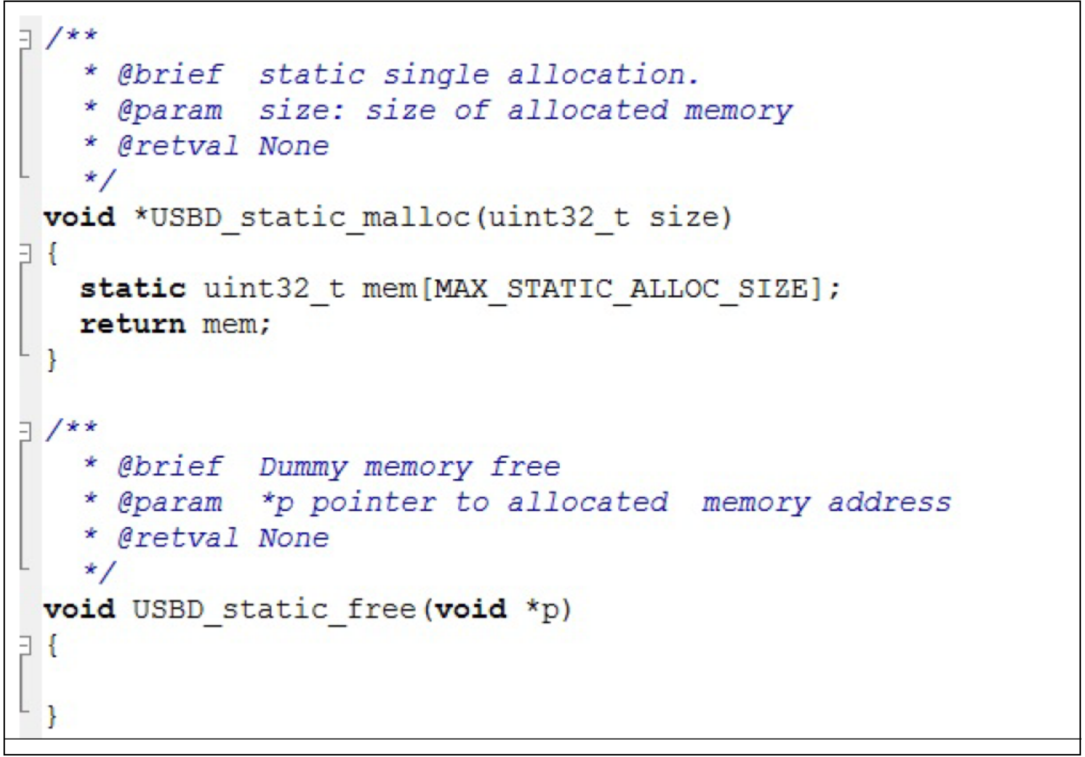
Below an example of implementation:

1. In usbd_conf.h file, define the memory static allocation and routines; *USBD_static_malloc()***and** *USBD_static_free()*

```
#define MAX_STATIC_ALLOC_SIZE 4 /* HID Class structure size */
#define USBD_malloc       (uint32_t *)USBD_static_malloc
#define USBD_free           USBD_static_free
```

2. The implementation is done in usbd_conf.c file as below:

Figure 21. Example of dynamic memory allocation for class structure



```
/**
  * @brief  static single allocation.
  * @param  size: size of allocated memory
  * @retval None
  */
void *USBD_static_malloc(uint32_t size)
{
  static uint32_t mem[MAX_STATIC_ALLOC_SIZE];
  return mem;
}

/**
  * @brief  Dummy memory free
  * @param  *p pointer to allocated  memory address
  * @retval None
  */
void USBD_static_free(void *p)
{

}
```

7 Frequently-asked questions

1. **How can the Device and string descriptors be modified on-the-fly?**

   In the *usbd_desc.c* file, the descriptor relative to the device and the strings can be modified using the Get Descriptor callbacks. The application can return the correct descriptor buffer relative to the application index using a switch case statement.

2. **How can the mass storage class driver support more than one logical unit (LUN)?**

   In the *usbd_msc_storage_template.c* file, all the APIs needed to use physical media are defined. Each function comes with the “LUN” parameter to select the addressed media.

   The number of supported LUNs can be changed using the define STORAGE_LUN_NBR in the *usbd_msc_storage_xxx.c* file (where, xxx is the medium to be used).

   For the inquiry data, the STORAGE_Inquirydata buffer contains the standard inquiry data for each LUN.

   Example: 2 LUNs are used

```
const int8_t  STORAGE_Inquirydata[] = {

   /* LUN 0 */
   0x00,
   0x80,
   0x02,
   0x02,
   (USBD_STD_INQUIRY_LENGTH - 5),
   0x00,
   0x00,
   0x00,
   'S', 'T', 'M', ' ', ' ', ' ', ' ', ' ', /* Manufacturer:
      8 bytes */
   'm', 'i', 'c', 'r', 'o', 'S', 'D', ' ', /* Product:
      16 Bytes */
   'F', 'l', 'a', 's', 'h', ' ', ' ', ' ',
   '1', '.', '0' ,'0', /* Version: 4 Bytes */

   /* LUN 0 */
   0x00,
   0x80,
   0x02,
   0x02,
   (USBD_STD_INQUIRY_LENGTH - 5),
   0x00,
   0x00,
   0x00,
   'S', 'T', 'M', ' ', ' ', ' ', ' ', ' ', /* Manufacturer:
      8 bytes */
'N', 'a', 'n', 'd', ' ', ' ', ' ', ' ', /* Product:
  16 Bytes */
'F', 'l', 'a', 's', 'h', ' ', ' ', ' ',
'1', '.', '0' ,'0', /* Version: 4 Bytes */
 };
```

3. **Where endpoints address are defined?**

   Endpoints address are defined in the header file of the class driver. In the case of the MSC demo case for example, the IN/OUT endpoints address are defined in the usbd_msc.h file as below:

   ```
   #define MSC_EPIN_ADDR      0x81 For Endpoint 1 IN
   #define MSC_EPOUT_ADDR     0x01 For Endpoint 1 OUT
   ```

4. **Can the USB device library be configured to run in either High Speed or Full Speed mode?**

   Yes, the library can handle the USB OTG HS and USB OTG FS core, if the USB OTG FS core can only work in Full Speed mode, the USB OTG HS can work in High or Full Speed mode.

   To select the appropriate USB Core to work with, user must add the following macro defines within the compiler preprocessor (already done in the preconfigured projects provided with the examples):

   - "USE_USB_HS" when using USB High Speed (HS) Core

   - "USE_USB_FS" when using USB Full Speed (FS) Core

   - "USE_USB_HS" and "USE_USB_HS_IN_FS" when using USB High Speed (HS) Core in FS mode

5. **How can the used endpoints be changed in the USB device class driver?**

   To change the endpoints or to add a new endpoint:

   a) Perform the endpoint initialization using USBD_LL_OpenEP().

   b) Configure the TX or the Rx FIFO size of the new defined endpoints in the *usb_conf.c* file using these APIs in the USBD_LL_Init() function

   – For STM32F2 and STM32F4 Series (FS and HS cores):

     HAL_PCD_SetRxFiFo()

     HAL_PCD_SetTxFiFo()

   The total size of the Rx and Tx FIFOs should be lower than the total FIFO size of the used core, that is 320 x 32 bits (1.25 Kbytes) for USB OTG FS core and 1024 x 32 bits (4 Kbytes) for the USB OTG HS core.

   – For STM32F0, STM32L0, STM32F1 and STM32F3 Series (FS core only): HAL_PCD_PMA_Config()

6. **Is the USB device library compatible with Real Time operating system (RTOS)?**

   Yes, The USB device library could be used with RTOS, the CMSIS RTOS wrapper is used to make abstraction with OS kernel.

8 Revision history

Table 31. Document revision history

Date	Revision	Changes
27-May-2014	1	Initial release.
28-Nov-2014	2	Updated *Section : Introduction*, *Figure 1: STM32Cube block diagram* and *Section 2.1: Overview* All figures: added missing titles, updated figure style and clarified color codes. updated sequence to use the driver in *Section 6.3.2: Device firmware upgrade (DFU) Class core files*, *Section 6.4.3: How to use this driver*, *Section 6.5.6: How to use* and *Section 6.6: Adding a custom class*.
27-May-2015	3	*Introduction* updated and merged with section *STM32Cube overview*.
20-Feb-2019	4	Updated *Introduction* and STM32Cube logo on cover page. Added *Table 1: Application products* and trademark on STM32Cube. Changed ‘STM32Cube firmware’ into ‘STM32Cube MCU Package’ in the whole document. Added *Section 1.2: General information*.