µC/USB Device™

Universal Serial Bus Device Stack

User's Manual

Micriµm

Press

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µC/USB Device User's Manual

uC-USB-Device User Manual

USB is likely the most successful communication interface in the history of computer systems, and is the de-facto standard for connecting computer peripherals.

Micrium's µC/USB-Device is a USB device stack designed specifically for embedded systems. Built from the ground up with Micrium's quality, scalability and reliability, it has gone through a rigorous validation process to comply with the USB 2.0 specification.

The first section of this space, uC-USB-Device User Manual, describes the inner-workings of USB and the way Micrium's µC/USB-Device stack can be used to simplify USB development. It also gives details about the various configuration values and their uses and a porting guide for the core and all the classes. Information such as overview, configuration possibilities, implementation details and examples of typical usage is also given for every available class.

The second section, µC/USB-Device Reference Manual, gives details about the various functions that are available in the stack. The functions from the core and every class are documented, to facilitate the development of any application.

The examples featured in this documentation space include USB devices with the most basic functionality that will allow you to understand the USB concepts covered in the first part of the space and at the same time, they provide a framework to quickly build devices such as:

- Microphone, speaker or headset (Audio Class)
- USB-to-serial adapter (Communications Device Class)
- Mouse or keyboard (Human Interface Device Class)
- Removable storage device (Mass Storage Class)
- USB medical device (Personal Healthcare Device Class)
- Custom device (Vendor Class)

About USB

This chapter presents a quick introduction to USB. The first section in this chapter introduces the basic concepts of the USB specification Revision 2.0. The second section explores the data flow model. The third section gives details about the device operation. Lastly, the fourth section describes USB device logical organization.

The full protocol is described extensively in the USB Specification Revision 2.0 at `http://www.usb.org`.

Introduction

The Universal Serial Bus (USB) is an industry standard maintained by the USB Implementers Forum (USB-IF) for serial bus communication. The USB specification contains all the information about the protocol such as the electrical signaling, the physical dimension of the connector, the protocol layer, and other important aspects. USB provides several benefits compared to other communication interfaces such as ease of use, low cost, low power consumption and, fast and reliable data transfer.

Bus Topology

USB can connect a series of devices using a tiered star topology. The key elements in USB topology are the *host*, *hubs*, and *devices*, as illustrated in Figure - USB Bus Topology in the *Introduction* page. Each node in the illustration represents a USB hub or a USB device. At the top level of the graph is the root hub, which is part of the host. There is only one host in the system. The specification allows up to seven tiers and a maximum of five non-root hubs in any path between the host and a device. Each tier must contain at least one hub except for the last tier where only devices are present. Each USB device in the system has a unique address assigned by the host through a process called *enumeration* (see section Enumeration for more details on enumeration).

The host learns about the device capabilities during enumeration, which allows the host operating system to load a specific driver for a particular USB device. The maximum number of peripherals that can be attached to a host is 127, including the root hub.

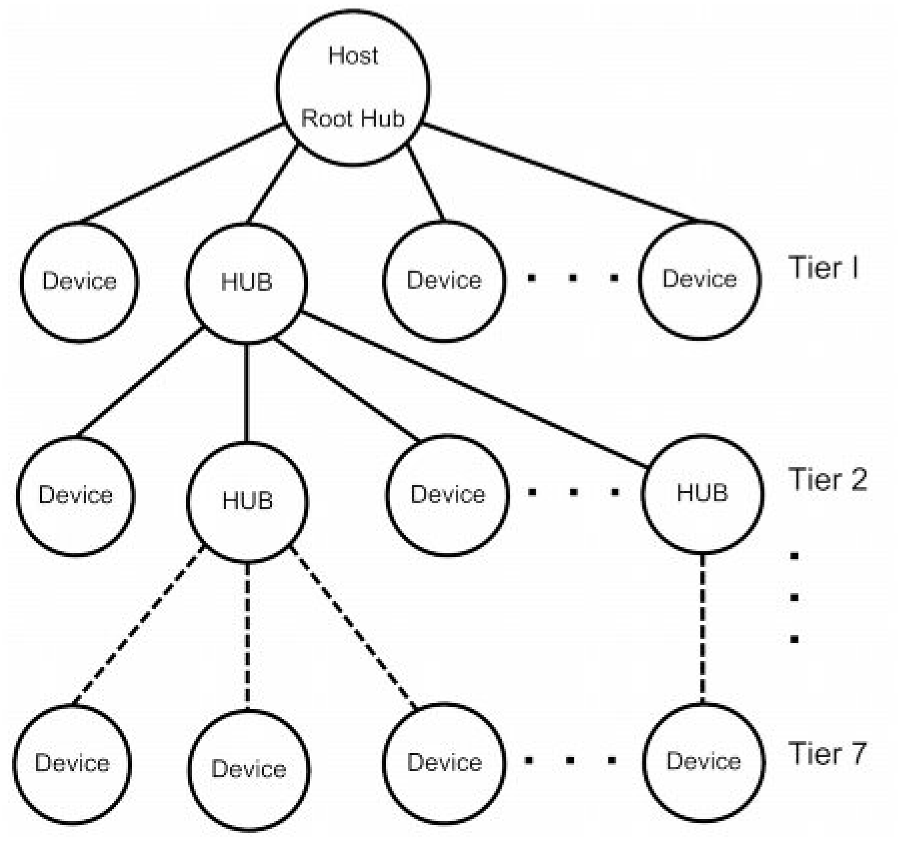


Figure - USB Bus Topology

USB Host

The USB host communicates with the devices using a USB host controller. The host is responsible for detecting and enumerating devices, managing bus access, performing error checking, providing and managing power, and exchanging data with the devices.

USB Device

A USB device implements one or more USB functions where a function provides one specific capability to the system. Examples of USB functions are keyboards, webcam, speakers, or a mouse. The requirements of the USB functions are described in the USB class specification. For example, keyboards and mice are implemented using the Human Interface Device (HID) specification.

USB devices must also respond to requests from the host. For example, on power up, or when a device is connected to the host, the host queries the device capabilities during enumeration, using standard requests.

Data Flow Model

This section defines the elements involved in the transmission of data across USB.

Endpoint

Endpoints function as the point of origin or the point of reception for data. An endpoint is a logical entity identified using an endpoint address. The endpoint address of a device is fixed, and is assigned when the device is designed, as opposed to the device address, which is assigned by the host dynamically during enumeration. An endpoint address consists of an endpoint number field (0 to 15), and a direction bit that indicates if the endpoint sends data to the host (IN) or receives data from the host (OUT). The maximum number of endpoints allowed on a single device is 32.

Endpoints contain configurable characteristics that define the behavior of a USB device:

- Bus access requirements
- Bandwidth requirement
- Error handling
- Maximum packet size that the endpoint is able to send or receive
- Transfer type
- Direction in which data is sent and receive from the host

Endpoint Zero Requirement

Endpoint zero (also known as Default Endpoint) is a bi-directional endpoint used by the USB host system to get information, and configure the device via standard requests. All devices must implement an endpoint zero configured for control transfers (see section Control Transfers for more information).

Pipes

A USB pipe is a logical association between an endpoint and a software structure in the USB host software system. USB pipes are used to send data from the host software to the device's endpoints. A USB pipe is associated to a unique endpoint address, type of transfer, maximum packet size, and interval for transfers.

The USB specification defines two types of pipes based on the communication mode:

- Stream Pipes: Data carried over the pipe is unstructured.

- Message Pipes: Data carried over the pipe has a defined structure.

Transfer Types

The USB specification requires a default control pipe for each device. A default control pipe uses endpoint zero. The default control pipe is a bi-directional message pipe.

The USB specification defines four transfer types that match the bandwidth and services requirements of the host and the device application using a specific pipe. Each USB transfer encompasses one or more transactions that send data to and from the endpoint. The notion of transactions is related to the maximum payload size defined by each endpoint type. That is, when a transfer is greater than this maximum, it will be split into one or more transactions to fulfill the action.

Control Transfers

Control transfers are used to configure and retrieve information about the device capabilities. They are used by the host to send standard requests during and after enumeration. Standard requests allow the host to learn about the device capabilities; for example, how many and which functions the device contains. Control transfers are also used for class-specific and vendor-specific requests.

A control transfer contains three stages: Setup, Data, and Status. These stages are listed in Table - Control Transfer Stages in the *Data Flow Model* page.

Stage	Description
Setup	The Setup stage includes information about the request. This SETUP stage represents one transaction.
Data	The Data stage contains data associated with request. Some standard and class-specific request may not require a Data stage. This stage is an IN or OUT directional transfer and the complete Data stage represents one ore more transactions.
Status	The Status stage, representing one transaction, is used to report the success or failure of the transfer. The direction of the Status stage is opposite to the direction of the Data stage. If the control transfer has no Data stage, the Status stage always is from the device (IN).

Table - Control Transfer Stages

Bulk Transfers

Bulk transfers are intended for devices that exchange large amounts of data where the transfer can take all of the available bus bandwidth. Bulk transfers are reliable, as error detection and retransmission mechanisms are implemented in hardware to guarantee data integrity. However, bulk transfers offer no guarantee on timing. Printers and mass storage devices are examples of devices that use bulk transfers.

Interrupt Transfers

Interrupt transfers are designed to support devices with latency constrains. Devices using interrupt transfers can schedule data at any time. Devices using interrupt transfer provide a polling interval which determines when the scheduled data is transferred over the bus. Interrupt transfers are typically used for event notifications.

Isochronous Transfers

Isochronous transfers are used by devices that require data delivery at a constant rate with a certain degree of error-tolerance. Retransmission is not supported by isochronous transfers. Audio and video devices use isochronous transfers.

USB Data Flow Model

Figure - USB Data Flow in the *Data Flow Model* page shows a graphical representation of the data flow model.

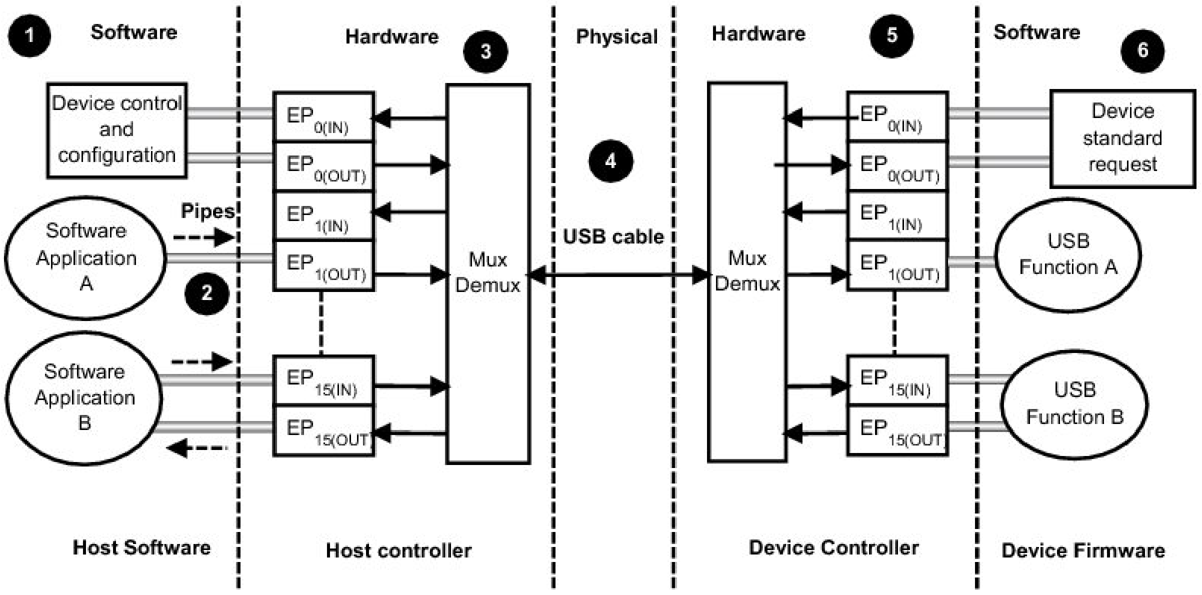


Figure - USB Data Flow

(1) The host software uses standard requests to query and configure the device using the default pipe. The default pipe uses endpoint zero (EP0).

(2) USB pipes allow associations between the host application and the device's endpoints. Host applications send and receive data through USB pipes.

(3) The host controller is responsible for the transmission, reception, packing and unpacking of data over the bus.

(4) Data is transmitted via the physical media.

(5) The device controller is responsible for the transmission, reception, packing and unpacking of data over the bus. The USB controller informs the USB device software layer about several events such as bus events and transfer events.

(6) The device software layer responds to the standard request, and implements one or more USB functions as specified in the USB class document.

Transfer Completion

The notion of transfer completion is only relevant for control, bulk and interrupt transfers as isochronous transfers occur continuously and periodically by nature. In general, control, bulk and interrupt endpoints must transmit data payload sizes that are less than or equal to the endpoint's maximum data payload size. When a transfer's data payload is greater than the maximum data payload size, the transfer is split into several transactions whose payload is maximum-sized except the last transaction which contains the remaining data. A transfer is deemed complete when:

- The endpoint transfers exactly the amount of data expected.
- The endpoint transfers a short packet, that is a packet with a payload size less than the maximum.
- The endpoint transfers a zero-length packet.

Physical Interface and Power Management

Physical Interface

USB transfers data and provides power using four-wire cables. The four wires are: Vbus, D+, D- and Ground. Signaling occurs on the D+ and D- wires.

Speed

The USB 2.0 specification defines three different speeds.

- Low Speed: 1.5 Mb/s
- Full Speed: 12 Mb/s
- High Speed: 480 Mb/s

Power Distribution

The host can supply power to USB devices that are directly connected to the host. USB devices may also have their own power supplies. USB devices that use power from the cable are called bus-powered devices. Bus-powered devices can draw a maximum of 500 mA from the host. USB devices that have an alternative source of power are called self-powered devices.

Device Structure and Enumeration

Before the host application can communicate with a device, the host needs to understand the capabilities of the device. This process takes place during device enumeration. After enumeration, the host can assign and load a specific driver to allow communication between the application and the device.

During enumeration, the host assigns an address to the device, reads descriptors from the device, and selects a configuration that specifies power and interface requirements. In order for the host to learn about the device's capabilities, the device must provide information about itself in the form of descriptors.

This section describes the device's logical organization from the USB host's point of view.

USB Device Structure

From the host's point of view, USB devices are internally organized as a collection of configurations, interfaces and endpoints.

Configuration

A USB configuration specifies the capabilities of a device. A configuration consists of a collection of USB interfaces that implement one or more USB functions. Typically only one configuration is required for a given device. However, the USB specification allows up to 255 different configurations. During enumeration, the host selects a configuration. Only one configuration can be active at a time. The device uses a configuration descriptor to inform the host about a specific configuration's capabilities.

Interface

A USB interface or a group of interfaces provides information about a function or class implemented by the device. An interface can contain multiple mutually exclusive settings called alternate settings. The device uses an interface descriptor to inform the host about a specific interface's capabilities. Each interface descriptor contains a class, subclass, and protocol codes defined by the USB-IF, and the number of endpoints required for a particular class implementation.

Alternate Settings

Alternate settings are used by the device to specify mutually exclusive settings for each interface. The default alternate settings contain the default settings of the device. The device also uses an interface descriptor to inform the host about an interface's alternate settings.

Endpoint

An interface requires a set of endpoints to communicate with the host. Each interface has different requirements in terms of the number of endpoints, transfer type, direction, maximum packet size, and maximum polling interval. The device sends an endpoint descriptor to notify the host about endpoint capabilities.

Figure - USB Device Structure in the *Device Structure and Enumeration* page shows the hierarchical organization of a USB device. Configurations are grouped based on the device's speed. A high-speed device might have a particular configuration in both high-speed and low/full speed.

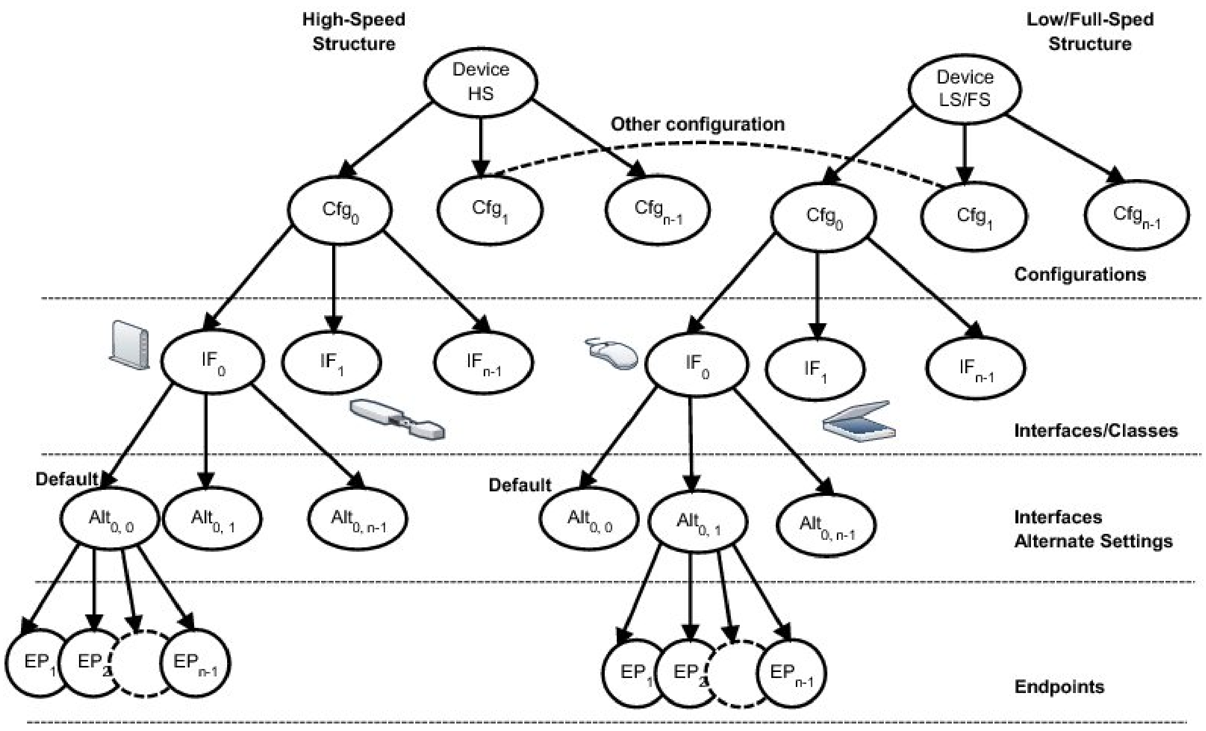


Figure - USB Device Structure

Device States

The USB 2.0 specification defines six different states and are listed in Table - USB Device States in the *Device Structure and Enumeration* page.

Device States	Description
Attached	The device is in the Attached state when it is connected to the host or a hub port. The hub must be connected to the host or to another hub.
Powered	A device is considered in the Powered state when it starts consuming power from the bus. Only bus-powered devices use power from the host. Self-powered devices are in the Powered state after port attachment.
Default	After the device has been powered, it should not respond to any request or transactions until it receives a reset signal from the host. The device enters in the Default state when it receives a reset signal from the host. In the Default state, the device responds to standard requests at the default address 0.
Address	During enumeration, the host assigns a unique address to the device. When this occurs, the device moves from the Default state to the Address state.
Configured	After the host assigns an address to the device, the host must select a configuration. After the host selects a configuration, the device enters the Configured state. In this state, the device is ready to communicate with the host applications.
Suspended	The device enters into Suspended state when no traffic has been seen over the bus for a specific period of time. The device retains the address assigned by the host in the Suspended state. The device returns to the previous state after traffic is present in the bus.

Table - USB Device States

Enumeration

Enumeration is the process where the host configures the device and learns about the device's capabilities. The host starts enumeration after the device is attached to one of the root or external hub ports. The host learns about the device's manufacturer, vendor/product IDs and release versions by sending a Get Descriptor request to obtain the device descriptor and the maximum packet size of the default pipe (control endpoint 0). Once that is done, the host assigns a unique address to the device which will tell the device to only answer requests at this unique address. Next, the host gets the capabilities of the device by a series of Get Descriptor requests. The host iterates through all the available configurations to retrieve information about number of interfaces in each configuration, interfaces classes, and endpoint parameters for each interface and will lastly finish the enumeration process by selecting the most suitable configuration.

Getting Started

This chapter gives you some insight into how to install and use the µC/USB-Device stack. The following topics are explained in this chapter:

- Prerequisites
- Downloading the source code files
- Installing the files
- Building the sample application
- Running the sample application

At the end of this chapter, you should be able to build and run your first USB application using the µC/USB-Device stack.

Installing the USB Device Stack

Prerequisites

Before running your first application, you must ensure that you have the minimal set of required tools and components:

- Toolchain for your specific microcontroller.
- Development board.
- µC/USB-Device stack with the source code of at least one of the Micrium USB classes.
- USB device controller driver compatible with your hardware for the µC/USB-Device stack.
- Board support package (BSP) for your development board.
- Example project for your selected RTOS (that is µC/OS-II or µC/OS-III).

If Micrium does not support your USB device controller or BSP, you will have to write your own device driver. Refer to Device Driver Guide for more information on writing your own USB device driver.

Downloading the Source Code

µC/USB-Device can be downloaded from the Micrium customer portal. The distribution package includes the full source code and documentation. You can log into the Micrium customer portal at the address below to begin your download (you must have a valid license to gain access to the file):

`http://micrium.com/customer-login/`

µC/USB-Device depends on other modules, and you need to install all the required modules before building your application. Depending on the availability of support for your hardware platform, ports and drivers may or may not be available for download from the customer portal. Table - μC/USB-Device Module Dependency in the *Installing the USB Device Stack* page shows the module dependency for μC/USB-Device.

Module Name	Required	Note(s)
μC/USB-Device Core	YES	Hardware independent USB stack.
μC/USB-Device Driver	YES	USB device controller driver. Available only if Micrium supports your controller, otherwise you have to develop it yourself.
μC/USB-Device Audio Class	Optional	Available only if you purchased the Audio class.
μC/USB-Device CDC ACM	Optional	Available only if you purchased the Communication Device Class (CDC) with the Abstract Control Model (ACM) subclass.
μC/USB-Device CDC EEM	Optional	Available only if you purchased the Communication Device Class (CDC) Ethernet Emulation Model (EEM) subclass.
μC/USB-Device HID Class	Optional	Available only if you purchased the Human Interface Device (HID) class.
μC/USB-Device MSC	Optional	Available only if you purchased the Mass Storage Class (MSC).
μC/USB-Device PHDC	Optional	Available only if you purchased the Personal Healthcare Device Class (PHDC).
μC/USB-Device Vendor Class	Optional	Available only if you purchased the Vendor class.
μC/CPU Core	YES	
μC/CPU Port	YES	Available only if Micrium has support for your processor architecture.
μC/LIB Core	YES	Micrium run-time library.
μC/LIB Port	Optional	Available only if Micrium has support for your processor architecture.
μC/OS-II Core	Optional	Available only if your application is using μC/OS-II.
μC/OS-II Port	Optional	Available only if Micrium has support for your processor architecture.
μC/OS-III Core	Optional	Available only if your application is using μC/OS-III.
μC/OS-III Port	Optional	Available only if Micrium has support for your processor architecture.

Table - μC/USB-Device Module Dependency

Table - μC/USB-Device Module Dependency in the *Installing the USB Device Stack* page indicates that all the μC/USB-Device classes are optional because there is no mandatory class to purchase with the μC/USB-Device Core and Driver. The class to purchase will depend on your needs. But don't forget that you need a class to build a complete USB project. Table - μC/USB-Device Module Dependency in the *Installing the USB Device Stack* page also indicates that μC/OS-II and -III Core and Port are optional. Indeed, μC/USB-Device stack does not assume a specific real-time operating system to work with, but it still requires one.

Installing the Files

Once all the distribution packages have been downloaded to your host machine, extract all the files at the root of your C:\ drive for instance. The package may be extracted to any location. After extracting all the files, the directory structure should look as illustrated in Figure - Directory Tree for µC/USB-Device in the *Installing the USB Device Stack* page. In the example, all Micrium products sub-folders shown in Figure - Directory Tree for µC/USB-Device in the *Installing the USB Device Stack* page will be located in `C:\Micrium\Software\`.

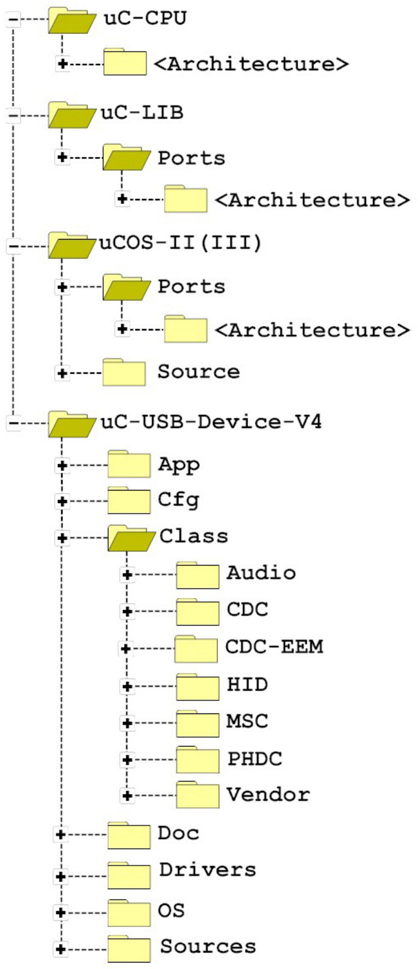


Figure - Directory Tree for µC/USB-Device

Building the Sample Application

This section describes all the steps required to build a USB-based application. The instructions provided in this section are not intended for any particular toolchain, but instead are described in a generic way that can be adapted to any toolchain.

The best way to start building a USB-based project is to start from an existing project. If you are using µC/OS-II or µC/OS-III, Micrium provides example projects for multiple development boards and compilers. If your target board is not listed on Micrium's web site, you can download an example project for a similar board or microcontroller.

The purpose of the sample project is to allow a host to enumerate your device. You will add a USB class instance to both, full-speed and high-speed configurations (if both are supported by your controller). Refer to the Class Instance Concept page for more details about the class instance concept. After you have successfully completed and run the sample project, you can use it as a starting point to run other USB class demos you may have purchased.

µC/USB-Device requires a Real-Time Operating System (RTOS). The following assumes that you have a working example project running on µC/OS-II or µC/OS-III.

Understanding Micrium Examples

A Micrium example project is usually placed in the following directory structure.

```
\Micrium
    \Software
        \EvalBoards
            \<manufacturer>
                \<board_name>
                    \<compiler>
                        \<project name>
                            \*.*
```

Note that Micrium does *not* provide by default an example project with the µC/USB-Device distribution package. Micrium examples are provided to customers in specific situations. If it happens that you receive a Micrium example, the directory structure shown above is generally used by Micrium. You may use a different directory structure to store the application and toolchain projects files.

`\Micrium`

This is where Micrium places all software components and projects. This directory is generally located at the root directory.

`\Software`

This sub-directory contains all software components and projects.

`\EvalBoards`

This sub-directory contains all projects related to evaluation boards supported by Micrium.

`\<manufacturer>`

This is the name of the manufacturer of the evaluation board. In some cases this can also be the name of the microcontroller manufacturer.

`\<board name>`

This is the name of the evaluation board.

`\<compiler>`

This is the name of the compiler or compiler manufacturer used to build the code for the evaluation board.

`\<project name>`

The name of the project that will be demonstrated. For example a simple µC/USB-Device with µC/OS-III project might have the project name 'uCOS-III-USBD'.

`\*.*`

These are the source files for the project. This directory contains configuration files `app_cfg.h`, `os_cfg.h`, `os_cfg_app.h`, `cpu_cfg.h` and other project-required sources files.

`os_cfg.h` is a configuration file used to configure µC/OS-III (or µC/OS-II) parameters such as the maximum number of tasks, events, objects, which µC/OS-III services are enabled (semaphores, mailboxes, queues), and so on. `os_cfg.h` is a required file for any µC/OS-III application. See the µC/OS-III documentation and books for further information.

`app.c` contains the application code for the example project. As with most C programs, code execution starts at `main()`. At a minimum, `app.c` initializes µC/OS-III and creates a startup task that initializes other Micrium modules.

`app_cfg.h` is a configuration file for your application. This file contains `#defines` to configure the priorities and stack sizes of your application and the Micrium modules' tasks.

`app_<module>.c` and `app_<module>.h` These optional files contain the Micrium modules' (µC/TCP-IP, µC/FS, µC/USB-Host, etc) initialization code. They may or may not be present in the example projects.

Copying and Modifying Template Files

Copy the files from the application template and configuration folders into your application as illustrated in Figure - Copying Template Files in the *Building the Sample Application* page.

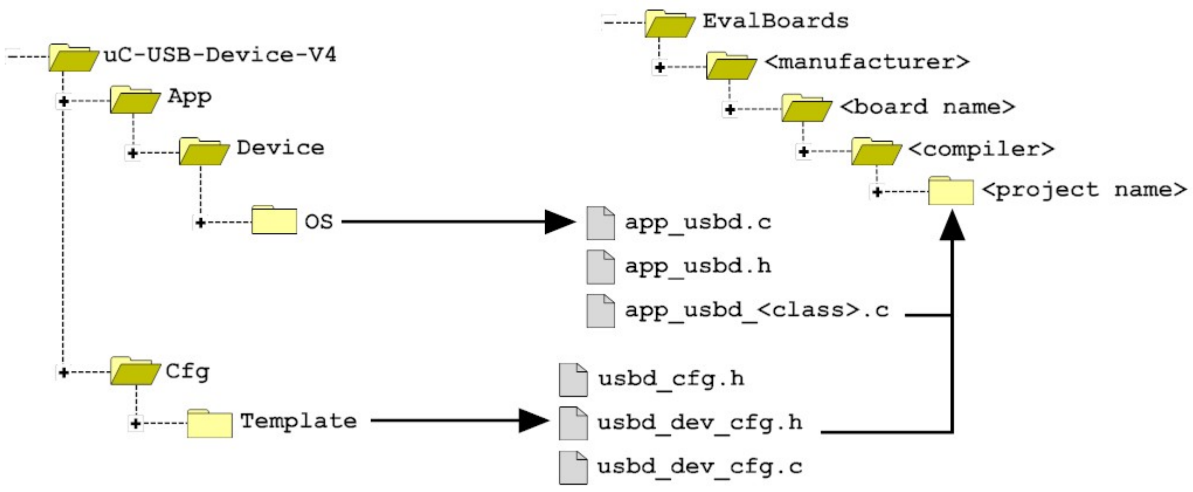


Figure - Copying Template Files

`app_usbd.*` is the master template for USB application-specific initialization code. This file contains the function `App_USBD_Init()`, which initializes the USB stack and class-specific demos.

`app_usbd_<class>.c` contains a template to initialize and use a certain class. This file contains the class demo application. In general, the class application initializes the class, creates a class instance, and adds the instance to the full-speed and high-speed configurations. Refer to the chapter(s) of the USB class(es) you purchased for more details about the USB class demos.

`usbd_cfg.h` is a configuration file used to setup µC/USB-Device stack parameters such as the maximum number of configurations, interfaces, or class-related parameters.

`usbd_dev_cfg.c` and `usbd_dev_cfg.h` are configuration files used to set device parameters such as vendor ID, product ID, and device release number. They are also necessary to configure the USB device controller driver parameters, such as base address, dedicated memory base address and size, controller’s speed, and endpoint capabilities.

Modify Device Configuration

Modify the device configuration file (`usbd_cfg.c`) as needed for your application. See Listing - Device Configuration Template in the *Building the Sample Application* page below for details.

```
USBD_DEV_CFG  USBD_DevCfg_Template = {                                          (1)
    0xFFFE,                                                                     (2)
    0x1234,
    0x0100,
   "OEM MANUFACTURER",                                                          (3)
   "OEM PRODUCT",
   "1234567890ABCDEF",
    USBD_LANG_ID_ENGLISH_US                                                     (4)
};
```

Listing - Device Configuration Template

(1) Give your device configuration a meaningful name by replacing the word “`Template`”.

(2) Assign the Vendor ID, Product ID and Device Release Number. For development purposes you can use the default values, but once you decide to release your product, you must contact the USB Implementers Forum (USB-IF) at *www.usb.org* in order to get valid IDs. USB-IF is a non-profit organization that among other activities, maintains all USB Vendor ID and Product ID numbers.

(3) Specify human readable Vendor ID, Product ID, and Device Release Number strings.

(4) A USB device can store strings in multiple languages. Specify the language used in your

strings. The #defines for the other languages are defined in the file `usbd_core.h` in the section “Language Identifiers”.

Modify Driver Configuration

Modify the driver configuration (`usbd_dev_cfg.c`) as needed for your controller. See Listing - Driver Configuration Template in the *Building the Sample Application* page below for details.

```
USBD_DRV_CFG USBD_DrvCfg_Template = {                                          (1)
    0x00000000,                                                                (2)
    0x00000000,                                                                (3)
    0u,
    USBD_DEV_SPD_FULL,                                                         (4)
    USBD_DrvEP_InfoTbl_Template                                                (5)
};
```

Listing - Driver Configuration Template

(1) Give your driver configuration a meaningful name by replacing the word “`Template`”.

(2) Specify the base address of your USB device controller.

(3) If your target has dedicated memory for the USB controller, you can specify its base address and size here. Depending on the USB controller, dedicated memory can be used to allocate driver buffers or DMA descriptors.

(4) Specify the USB device controller speed: `USBD_DEV_SPD_HIGH` if your controller supports high-speed or `USBD_DEV_SPD_FULL` if your controller supports only full-speed.

(5) Specify the endpoint information table. The endpoint information table should be defined in your USB device controller BSP files. Refer to Endpoint Information Table for more details on the endpoint information table.

Modify USB Application Initialization Code

Listing - App_USBD_Init() in app_usbd.c in the *Building the Sample Application* page shows the code that you should modify based on your specific configuration done previously. You should modify the parts that are highlighted by the text in bold. The code snippet is extracted from the function `App_USBD_Init()` defined in `app_usbd.c`. The complete initialization sequence performed by `App_USBD_Init()` is presented in Listing - App_USBD_Init() Function in the *Running the Sample Application* page.

```
#include  <usbd_bsp_template.h>                                            (1)

CPU_BOOLEAN  App_USBD_Init (void)
{
    CPU_INT08U   dev_nbr;
    CPU_INT08U   cfg_fs_nbr;
    USBD_ERR     err;


    USBD_Init(&err);                                                       (2)

    dev_nbr = USBD_DevAdd(&USBD_DevCfg_Template,                           (3)
                          &App_USBD_BusFncts,                              (4)
                          &USBD_DrvAPI_Template,                           (5)
                          &USBD_DrvCfg_Template,                           (6)
                          &USBD_DrvBSP_Template,                           (7)
                          &err);

    if (USBD_DrvCfg_Template.Spd == USBD_DEV_SPD_HIGH) {                   (8)
        cfg_hs_nbr = USBD_CfgAdd(dev_nbr,
                                 USBD_DEV_ATTRIB_SELF_POWERED,
                                 100u,
                                 USBD_DEV_SPD_HIGH,
                                "HS configuration",
                                &err);
    }
....
}
```

Listing - App_USBD_Init() in app_usbd.c

(1) Include the USB driver BSP header file that is specific to your board. This file can be found in the following folder:
`\Micrium\Software\uC-USB-Device\Drivers\<controller>\BSP\<board name>`

(2) Initialize the USB device stack’s internal variables, structures and core RTOS port.

(3) Specify the address of the device configuration structure that you modified in the section

"Modify Device Configuration".

(4) Specify the address of the Bus Event callbacks structure. See section Bus Event Callback Structure for more details on this structure.

(5) Specify the address of the driver’s API structure. The driver’s API structure is defined in the driver’s header file named `usbd_drv_<controller>.h`.

(6) Specify the address of the driver configuration structure that you modified in the section “Modify Driver Configuration”.

(7) Specify the address of the driver’s BSP API structure. The driver’s BSP API structure is defined in the driver’s BSP header file named `usbd_bsp_<controller>.h`.

(8) If the device controller supports high-speed, create a high-speed configuration for the specified device.

Including USB Device Stack Source Code

First, include the following files in your project from the µC/USB-Device source code distribution, as indicated in Listing - µC/USB-Device Source Code in the *Building the Sample Application* page.

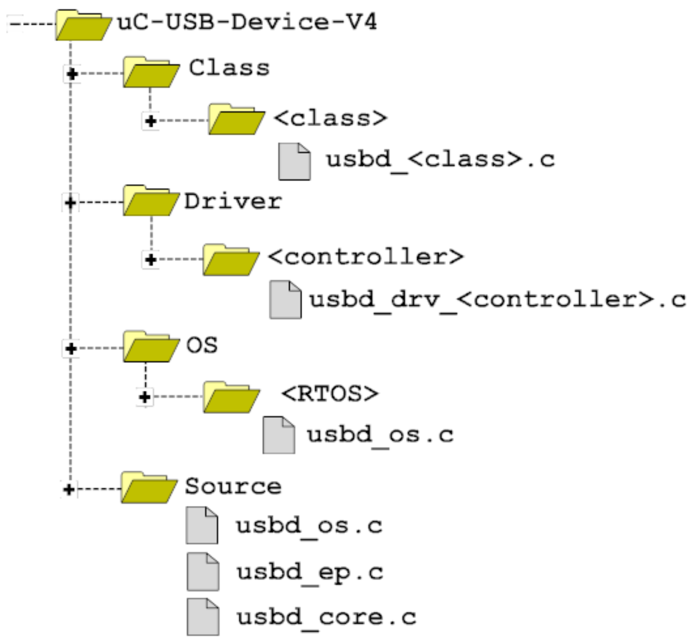


Figure - µC/USB-Device Source Code

Second, add the following include paths to your project's C compiler settings:

```
\Micrium\Software\uC-USB-Device-V4\
```

If you are using the MSC class, add the following include path:

```
\Micrium\Software\uC-USB-Device-V4\Class\MSC\Storage\<storage name>
```

Modifying the Application Configuration File

The USB application initialization code templates assume the presence of `app_cfg.h`. The following `#defines` must be present in `app_cfg.h` in order to build the sample application.

```
#define  APP_CFG_USBD_EN                        DEF_ENABLED                  (1)

#define  USBD_OS_CFG_CORE_TASK_PRIO                      6u                  (2)
#define  USBD_OS_CFG_TRACE_TASK_PRIO                     7u
#define  USBD_OS_CFG_CORE_TASK_STK_SIZE                256u
#define  USBD_OS_CFG_TRACE_TASK_STK_SIZE               256u

#define  LIB_MEM_CFG_OPTIMIZE_ASM_EN            DEF_DISABLED                 (3)
#define  LIB_MEM_CFG_ARG_CHK_EXT_EN             DEF_ENABLED
#define  LIB_MEM_CFG_ALLOC_EN                   DEF_ENABLED
#define  LIB_MEM_CFG_HEAP_SIZE                        1024u

#define  TRACE_LEVEL_OFF                                 0u                  (4)
#define  TRACE_LEVEL_INFO                                1u
#define  TRACE_LEVEL_DBG                                 2u

#define  APP_CFG_TRACE_LEVEL                    TRACE_LEVEL_DBG              (5)
#define  APP_CFG_TRACE                          printf                       (6)

#define  APP_TRACE_INFO(x)   ((APP_CFG_TRACE_LEVEL >= TRACE_LEVEL_INFO)  ? (void)(APP_CFG_TRACE x) :
(void)0)
#define  APP_TRACE_DBG(x)    ((APP_CFG_TRACE_LEVEL >= TRACE_LEVEL_DBG)   ? (void)(APP_CFG_TRACE x) :
(void)0)
```

Listing - Application Configuration #defines

(1) `APP_CFG_USBD_EN` enables or disables the USB application initialization code.

(2) These #defines relate to the µC/USB-Device OS port. The µC/USB-Device core requires only one task to manage control requests and asynchronous transfers, and a second, optional task to output trace events (if trace capability is enabled). To properly set the priority of the core and debug tasks, refer to Task Priorities.

(3) Configure the desired size of the heap memory. Heap memory used for µC/USB-Device drivers that use internal buffers and DMA descriptors which are allocated at run-time and to allocate internal buffers that require memory alignment. Refer to the µC/LIB documentation for more details on the other µC/LIB constants.

(4) Most Micrium examples contain application trace macros to output human-readable debugging information. Two levels of tracing are enabled: INFO and DBG. INFO traces high-level operations, and DBG traces high-level operations and return errors. Application-level tracing is different from µC/USB-Device tracing (refer to Debug and Trace for more details).

(5) Define the application trace level.

(6) Specify which function should be used to redirect the output of human-readable application tracing. You can select the standard output via `printf()`, or another output such as a text terminal using a serial interface.

Besides the file `app_cfg.h`, another application file, `app_usbd_cfg.h`, specific to class demos should be modified according to the class(es) you want to play with. For that, the following `#defines` allows you to enable class demos.

```
#define  APP_CFG_USBD_AUDIO_EN                  DEF_DISABLED                  (1)
#define  APP_CFG_USBD_CDC_EN                    DEF_ENABLED
#define  APP_CFG_USBD_CDC_EEM_EN                DEF_ENABLED
#define  APP_CFG_USBD_HID_EN                    DEF_DISABLED
#define  APP_CFG_USBD_MSC_EN                    DEF_DISABLED
#define  APP_CFG_USBD_PHDC_EN                   DEF_DISABLED
#define  APP_CFG_USBD_VENDOR_EN                 DEF_DISABLED
```

Listing - USB Application Configuration #defines

(1) This `#define` enables the USB class-specific demo. You can enable one or more USB class-specific demos. If you enable several USB class-specific demos, your device will be a composite device.

`app_usbd_cfg.h` contains also other `#defines` specific to each class. Refer to the proper class application configuration section presented in this table for more details.

µC/USB-Device Class	Application Configuration page
Audio Class	Using the Audio Class Demo Application
Communications Device Class (CDC) Abstract Control Model (ACM)	Using the ACM Subclass Demo Application
Communications Device Class (CDC) Ethernet Emulation Model (EEM)	CDC EEM Demo Application
Human Interface Device Class (HID)	Using the HID Class Demo Application
Mass Storage Class (MSC)	Using the MSC Demo Application
Personal Healthcare Device Class (PHDC)	Using the PHDC Demo Application
Vendor Class	Using the Vendor Class Demo Application

Table - USB Class Application Configuration References

Every USB class also needs to have certain constants defined to work correctly. Table - USB Class Configuration References in the *Building the Sample Application* page presents the section to refer to based on the USB class.

μC/USB-Device Class	Configuration page
Audio Class	Audio Class General Configuration
Communications Device Class (CDC)	CDC General Configuration
Communications Device Class (CDC) Ethernet Emulation Model (EEM)	CDC EEM Subclass Configuration
Human Interface Device Class (HID)	HID Class General Configuration
Mass Storage Class (MSC)	MSC General Configuration
Personal Healthcare Device Class (PHDC)	PHDC General configuration
Vendor Class	Vendor Class General Configuration

Table - USB Class Configuration References

Running the Sample Application

The first step to integrate the demo application into your application code is to call `App_USBD_Init()`. This function is responsible for the following steps:

1. Initializing the USB device stack.
2. Creating and adding a device instance.
3. Creating and adding configurations.
4. Calling USB class-specific application code.
5. Starting the USB device stack.

The `App_USBD_Init()` function is described in Listing - App_USBD_Init() Function in the *Running the Sample Application* page.

```
CPU_BOOLEAN  App_USBD_Init (void)
{
    CPU_INT08U   dev_nbr;
    CPU_INT08U   cfg_hs_nbr;
    CPU_INT08U   cfg_fs_nbr;
    CPU_BOOLEAN  ok;
    USBD_ERR     err;


    USBD_Init(&err);                                                        (1)
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle error. */
        return (DEF_FAIL);
    }

    dev_nbr = USBD_DevAdd(&USBD_DevCfg_<controller>,                        (2)
                          &App_USBD_BusFncts,
                          &USBD_DrvAPI_<controller>,
                          &USBD_DrvCfg_<controller>,
                          &USBD_DrvBSP_<board name>,
                          &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle error. */
        return (DEF_FAIL);
    }
    cfg_hs_nbr = USBD_CFG_NBR_NONE;
    cfg_fs_nbr = USBD_CFG_NBR_NONE;

    if (USBD_DrvCfg_<controller>.Spd == USBD_DEV_SPD_HIGH) {

        cfg_hs_nbr = USBD_CfgAdd(dev_nbr,                                   (3)
                                  USBD_DEV_ATTRIB_SELF_POWERED,
                                  100u,
                                  USBD_DEV_SPD_HIGH,
                                 "HS configuration",
                                 &err);
        if (err != USBD_ERR_NONE) {
            /* $$$$ Handle error. */
            return (DEF_FAIL);
        }
    }

    cfg_fs_nbr = USBD_CfgAdd(dev_nbr,                                       (4)
                              USBD_DEV_ATTRIB_SELF_POWERED,
                              100u,
                              USBD_DEV_SPD_FULL,
                             "FS configuration",
                             &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle error. */
        return (DEF_FAIL);
    }

    if ((cfg_fs_nbr != USBD_CFG_NBR_NONE) &&
        (cfg_hs_nbr != USBD_CFG_NBR_NONE)) {
        USBD_CfgOtherSpeed(dev_nbr,                                         (5)
                           cfg_hs_nbr,
                           cfg_fs_nbr,
                          &err);
        if (err != USBD_ERR_NONE) {
            /* $$$$ Handle error. */
            return (DEF_FAIL);
        }
    }

#if (APP_CFG_USBD_XXXX_EN == DEF_ENABLED)                                   (6)
    ok = App_USBD_XXXX_Init(dev_nbr,
                              cfg_hs_nbr,
                              cfg_fs_nbr);
    if (ok != DEF_OK) {
       /* $$$$ Handle error. */
       return (DEF_FAIL);
    }
#endif
if (APP_CFG_USBD_XXXX_EN == DEF_ENABLED)                                       (6)
    .
    .
    .
#endif

    USBD_DevStart(dev_nbr, &err);                                              (7)

    (void)ok;
    return (DEF_OK);
}
```

Listing - App_USBD_Init() Function

(1) `USBD_Init()` initializes the USB device stack. This must be the first USB function called by your application's initialization code. If µC/USB-Device is used with µC/OS-II or -III, `OSInit()` must be called prior to `USBD_Init()` in order to initialize the kernel services.

(2) `USBD_DevAdd()` creates and adds a USB device instance. A given USB device instance is associated with a single USB device controller. µC/USB-Device can support multiple USB device controllers concurrently. If your target supports multiple controllers, you can create multiple USB device instances for them. The function `USBD_DevAdd()` returns a device instance number; this number is used as a parameter for all subsequent operations.

(3) Create and add a high-speed configuration to your device. `USBD_CfgAdd()` creates and adds a configuration to the USB device stack. At a minimum, your USB device application only needs one full-speed and one high-speed configuration if your device is a high-speed capable device. For a full-speed device, only a full-speed configuration will be required. You can create as many configurations as needed by your application, and you can associate multiple instances of USB classes to these configurations. For example, you can create a configuration to contain a mass storage device, and another configuration for a human interface device such as a keyboard, and a vendor specific device.

(4) Create and add a full-speed configuration to your device.

(5) Associate the high-speed configuration to it's full-speed counterpart. This inform the stack that both configurations offer comparable functionality regardless of speed. This is useful to generate the "Other Speed Configuration" descriptor.

(6) Initialize the class-specific application demos by calling the function `App_USBD_XXXX_Init()` where `XXXX` can be `CDC, HID, MSC, PHDC` or `VENDOR`. Class-specific demos are enabled and disabled using the `APP_CFG_USB_XXXX_EN` #define.

(7) After all the class instances are created and added to the device configurations, the application should call `USBD_DevStart()`. This function connects the device with the host by enabling the pull-up resistor on the D+ line.

Table - USB Class Demos Init Functions in the *Running the Sample Application* page lists the sections you should refer to for more details about each `App_USBD_XXXX_Init()` function.

Class	Function	Refer to...
Audio	`App_USBD_Audio_Init()`	Audio Class Configuration
CDC ACM	`App_USBD_CDC_Init()`	CDC Configuration
HID	`App_USBD_HID_Init()`	HID Class Configuration
MSC	`App_USBD_MSC_Init()`	MSC Configuration
PHDC	`App_USBD_PHDC_Init()`	PHDC Configuration
Vendor	`App_USBD_Vendor_Init()`	Vendor Class Configuration

Table - USB Class Demos Init Functions

After building and downloading the application into your target, you should be able to successfully connect your target to a host PC through USB. Once the USB sample application is running, the host detects the connection of a new device and starts the enumeration process. If you are using a Windows PC, it will load a driver which will manage your device. If no driver is found for your device, Windows will display the "found new hardware" wizard so that you can specify which driver to load. Once the driver is loaded, your device is ready for communication. Table - USB Class Demos References in the *Running the Sample Application* page lists the different section(s) you should refer to for more details on each USB class demo.

Class	Refer to...
Audio	Using the Demo Application (Audio)
CDC ACM	Using the Demo Application (CDC-ACM)
HID	Using the Demo Application (HID Class)
MSC	Using the Demo Application (MSC)
PHDC	Using the Demo Application (PHDC)
Vendor	Using the Demo Application (Vendor Class)

Table - USB Class Demos References

Host Operating Systems

The major host operating systems (OS), such as Microsoft Windows, Apple Mac OS and Linux, recognize a wide range of USB devices that belong to standard classes defined by the USB Implementers Forum. Upon connection of the USB device, any host operating system performs the following general steps:

1. Enumerating the USB device to learn about its characteristics.

2. Loading a proper driver according to its characteristics' analysis in order to manage the device.

3. Communicating with the device.

Step 2, where a driver is loaded to handle the device is performed differently by each major host operating system. Usually, a native driver provided by the operating system manages a device complying to a standard class (for instance, Audio, HID, MSC, Video, etc.) In this case, the native driver loading process is transparent to you. In general, the OS won't ask you for specific actions during the driver loading process. On the other hand, a vendor-specific device requires a vendor-specific driver provided by the device manufacturer. Vendor-specific devices don't fit into any standard class or don't use the standard protocols for an existing standard class. In this situation, the OS may explicitly ask for your intervention during the driver loading process.

During step 3, your application may have to find the USB device attached to the OS before communication with it. Each major OS uses a different method to allow you to find a specific device.

This page gives you the necessary information in case your intervention is required during the USB device driver loading process and in case your application needs to find a device attached to the computer. For the moment, this chapter describes this process only for the Windows operating system.

Microsoft Windows

Microsoft offers class drivers for some standard USB classes. These drivers can also be called native drivers. A complete list of the native drivers can be found in the MSDN online documentation on the page titled “USB class drivers included in Windows”. If a connected device belongs to a class for which a native driver exists, Windows automatically loads the driver without any additional actions from you. If a vendor-specific driver is required for the device, a manufacturer’s INF file giving instructions to Windows for loading the vendor-specific driver is required. In some cases, a manufacturer’s INF file may also be required to load a native driver.

When the device has been recognized by Windows and is ready for communication, your application may need to use a Globally Unique IDentifier (GUID) to retrieve a device handle that allows your application to communicate with the device.

The following sections explain the use of INF files and GUIDs. Table - Micrium USB Classes Concerned by Windows USB Device Management in the *Microsoft Windows* page shows the USB classes to which the information in the following sub-sections applies.

Section	Micrium USB classes
About INF Files	CDC, PHDC and Vendor
Using GUIDs	HID, PHDC and Vendor

Table - Micrium USB Classes Concerned by Windows USB Device Management

About INF Files

An INF file is a setup information file that contains information used by Windows to install software and drivers for one or more devices. The INF file also contains information to store in the Windows registry. Each of the drivers provided natively with the operating system has an associated INF file stored in `C:\WINDOWS\inf`. For instance, when an HID or MSC device is connected to the PC, Windows enumerates the device and implicitly finds an INF file associated to an HID or MSC class that permits loading the proper driver. INF files for native drivers are called system INF files. Any new INF files provided by manufacturers for vendor-specific devices are copied into the folder `C:\WINDOWS\inf`. These INF files can be called vendor-specific INF files. An INF file allows Windows to load one or more drivers for a device. A driver can be native or provided by the device manufacturer.

Table - Windows Drivers Loaded for each Micrium USB Class in the *Microsoft Windows* page shows the Windows driver(s) loaded for each Micrium USB class:

Micrium class	Windows driver	Driver type	INF file type
Audio	`Usbaudio.sys`	Native	System INF file
CDC ACM	`usbser.sys`	Native	Vendor-specific INF file
HID	`Hidclass.sys` `Hidusb.sys`	Native	System INF file
MSC	`Usbstor.sys`	Native	System INF file
HDCP	`winusb.sys` (for getting started purpose only).	Native	Vendor-specific INF file
Vendor	`winusb.sys`	Native	Vendor-specific INF file

Table - Windows Drivers Loaded for each Micrium USB Class

When a device is first connected, Windows searches for a match between the information contained in system INF files and the information retrieved from device descriptors. If there is no match, Windows asks you to provide an INF file for the connected device.

An INF file is arranged in sections whose names are surrounded by square brackets []. Each section contains one or several entries. If the entry has a predefined keyword such as “Class”, “Signature”, etc, the entry is called a directive. Listing - Example of INF File Structure in the *Microsoft Windows* page presents an example of an INF file structure:

```
; ================== Version section ====================
[Version]                                                                    (1)
Signature = "$Windows NT$"
Class     = Ports
ClassGuid = {4D36E978-E325-11CE-BFC1-08002BE10318}

Provider=%ProviderName%
DriverVer=01/01/2012,1.0.0.0

; ========== Manufacturer/Models sections =================

[Manufacturer]                                                               (2)
%ProviderName% = DeviceList, NTx86, NTamd64

[DeviceList.NTx86]                                                           (3)
%PROVIDER_CDC% = DriverInstall, USB\VID_fffe&PID_1234&MI_00
[DeviceList.NTamd64]                                                         (3)
%PROVIDER_CDC% = DriverInstall, USB\VID_fffe&PID_1234&MI_00

; ================ Installation sections ==================                  (4)

[DriverInstall]
include   = mdmcpq.inf
CopyFiles = FakeModemCopyFileSection
AddReg    = LowerFilterAddReg,SerialPropPageAddReg

[DriverInstall.Services]
include    = mdmcpq.inf
AddService = usbser, 0x00000002, LowerFilter_Service_Inst

[SerialPropPageAddReg]
HKR,,EnumPropPages32,,"MsPorts.dll,SerialPortPropPageProvider"

; ================= Strings section =====================
[Strings]                                                                    (5)
ProviderName = "Micrium"
PROVIDER_CDC = "Micrium CDC Device"
```

Listing - Example of INF File Structure

(1) The section `[Version]` is mandatory and informs Windows about the provider, the version and other descriptive information about the driver package.

(2) The section `[Manufacturer]` is mandatory. It identifies the device's manufacturer.

(3) The following two sections are called Models sections and are defined on a per-manufacturer basis. They give more detailed instructions on the driver(s) to install for the device(s). A section name can use extensions to specify OSes and/or CPUs the entries apply to. In this example, `.NTx86` and `.NTamd64` indicate that the driver can be installed on an NT-based Windows (that is Windows 2000 and later), on x86- and x64-based PC respectively.

(4) The installation sections actually install the driver(s) for each device described in the Model section(s). The driver installation may involve reading existing information from the Windows registry, modifying existing entries of the registry or creating new entries into the registry.

(5) The section `[Strings]` is mandatory and it is used to define each string key token indicated by `%string name%` in the INF file.

Refer to the MSDN online documentation on this web page for more details about INF sections and directives: `http://msdn.microsoft.com/en-us/library/ff549520.aspx` .

You will be able to modify some sections in order to match the INF file to your device characteristics, such as Vendor ID, Product ID and human-readable strings describing the device. The sections are:

- Models section
- `[Strings]` section

To identify possible drivers for a device, Windows looks in the Models section for a device identification string that matches a string created from information in the device's descriptors. Every USB device has a device ID, that is a hardware ID created by the Windows USB host stack from information contained in the Device descriptor. A device ID has the following form:

```
USB\Vid_xxxx&Pid_yyyy
```

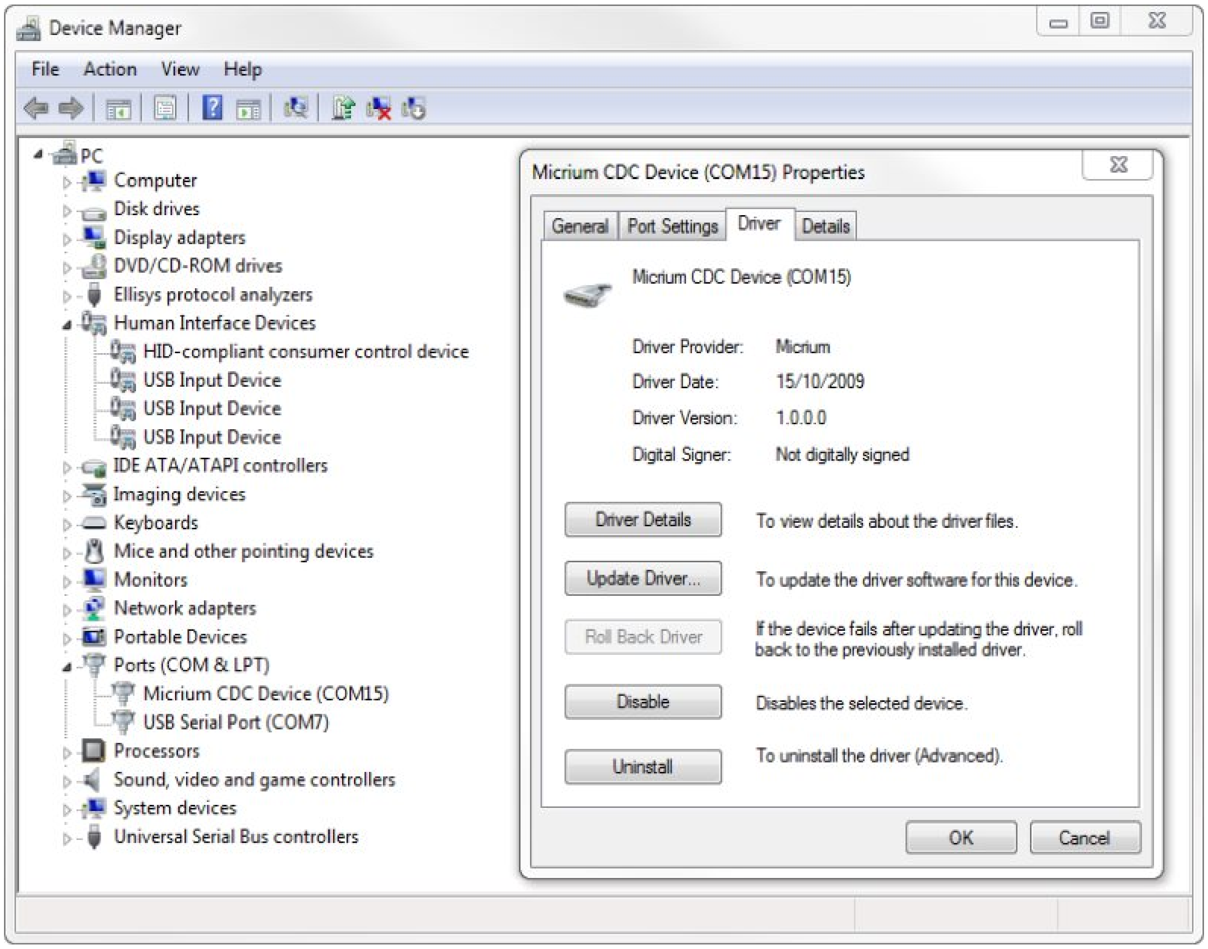
`xxxx`, `yyyy`, represent the value of the Device descriptor fields "idVendor" and "idProduct" respectively (refer to the Universal Serial Bus Specification, revision 2.0, section 9.6.1 for more details about the Device descriptor fields). This string allows Windows to load a driver for the device. You can modify `xxxx` and `yyyy` to match your device's Vendor and Product IDs. In Listing - Device Configuration Template in the *Building the Sample Application* page, the hardware ID defines the Vendor ID `0xFFFE` and the Product ID `0x1234`.

Composite devices, formed of several functions, can specify a driver for each function. In this case, the device has a device ID for each interface that represents a function. A device ID for an interface has the following form:

```
USB\Vid_xxxx&Pid_yyyy&MI_ww
```

`ww` is equal to the “bInterfaceNumber” field in the Interface descriptor (refer to the Universal Serial Bus Specification, revision 2.0, section 9.6.5 for more details on the Interface descriptor fields). You can modify `ww` to match the position of the interface in the Configuration descriptor. If the interface has the position #2 in the Configuration descriptor, `ww` is equals to 02.

The `[Strings]` section contains a description of your device. In Listing - Example of INF File Structure in the *Microsoft Windows* page, the strings define the name of the device driver package provider and the device name. You can see these device description strings in the Device Manager. For instance, Figure - Windows Device Manager Example for a CDC Device in the *Microsoft Windows* page shows a virtual COM port created with the INF file from Listing - Example of INF File Structure in the *Microsoft Windows* page. The string “Micrium” appears under the “Driver Provider” name in the device properties. The string “Micrium CDC Device” appears under the “Ports” group and in the device properties dialog box.



Micrium CDC Device (COM15)

Driver Provider: Micrium
Driver Date: 15/10/2009
Driver Version: 1.0.0.0
Digital Signer: Not digitally signed

To view details about the driver files.
To update the driver software for this device.
If the device fails after updating the driver, roll back to the previously installed driver.
Disables the selected device.
To uninstall the driver (Advanced).

Figure - Windows Device Manager Example for a CDC Device

Using GUIDs

A Globally Unique IDentifier (GUID) is a 128-bit value that uniquely identifies a class or other entity. Windows uses GUIDs for identifying two types of device classes:

- Device setup class
- Device interface class

A device setup GUID encompasses devices that Windows installs in the same way and using the same class installer and co-installers. Class installers and co-installers are DLLs that provide functions related to device installation. There is a GUID associated with each device setup class. System-defined setup class GUIDs are defined in devguid.h. The device setup class GUID defines the `..\CurrentControlSet\Control\Class\ClassGuid` registry key under which to create a new subkey for any particular device of a standard setup class. A complete list of system-defined device setup classes offered by Microsoft Windows® is available on MSDN online documentation.

A device interface class GUID provides a mechanism for applications to communicate with a driver assigned to devices in a class. A class or device driver can register one or more device interface classes to enable applications to learn about and communicate with devices that use the driver. Each device interface class has a device interface GUID. Upon a device's first attachment to the PC, the Windows I/O manager associates the device and the device interface class GUID with a symbolic link name, also called a device path. The device path is stored in the Windows registry and persists across system reboot. An application can retrieve all the connected devices within a device interface class. If the application has gotten a device path for a connected device, this device path can be passed to a function that will return a handle. This handle is passed to other functions in order to communicate with the corresponding device.

Three of Micrium's USB classes are provided with Visual Studio 2010 projects. These Visual Studio projects build applications that interact with a USB device. They use a device interface class GUID to detect any attached device belonging to the class. Table - Micrium Class and Device Interface Class GUID in the *Microsoft Windows* page shows the Micrium class and the corresponding device interface class GUID used in the class Visual Studio project.

Micrium USB class	Device interface class GUID	Defined in
HID	`{4d1e55b2-f16f-11cf-88cb-001111000030}`	`app_hid_common.h`
PHDC	`{143f20bd-7bd2-4ca6-9465-8882f2156bd6}`	`usbdev_guid.h`
Vendor	`{143f20bd-7bd2-4ca6-9465-8882f2156bd6}`	`usbdev_guid.h`

Table - Micrium Class and Device Interface Class GUID

The interface class GUID for the HID class is provided by Microsoft as part of system-defined device interface classes, whereas the interface class GUID for PHDC and Vendor classes have been generated with Visual Studio 2010 using the utility tool, `guidgen.exe`. This tool is accessible from the menu Tools and the option Create GUID or, through the command-line by selecting the menu Tools, option Visual Studio Command Prompt and by typing `guidgen` at the prompt.

Architecture

µC/USB-Device was designed to be modular and easy to adapt to a variety of Central Processing Units (CPUs), Real-Time Operating Systems (RTOS), USB device controllers, and compilers.

Figure - µC/USB-Device Architecture Block Diagram in the *Architecture* page shows a simplified block diagram of all the µC/USB-Device modules and their relationships.

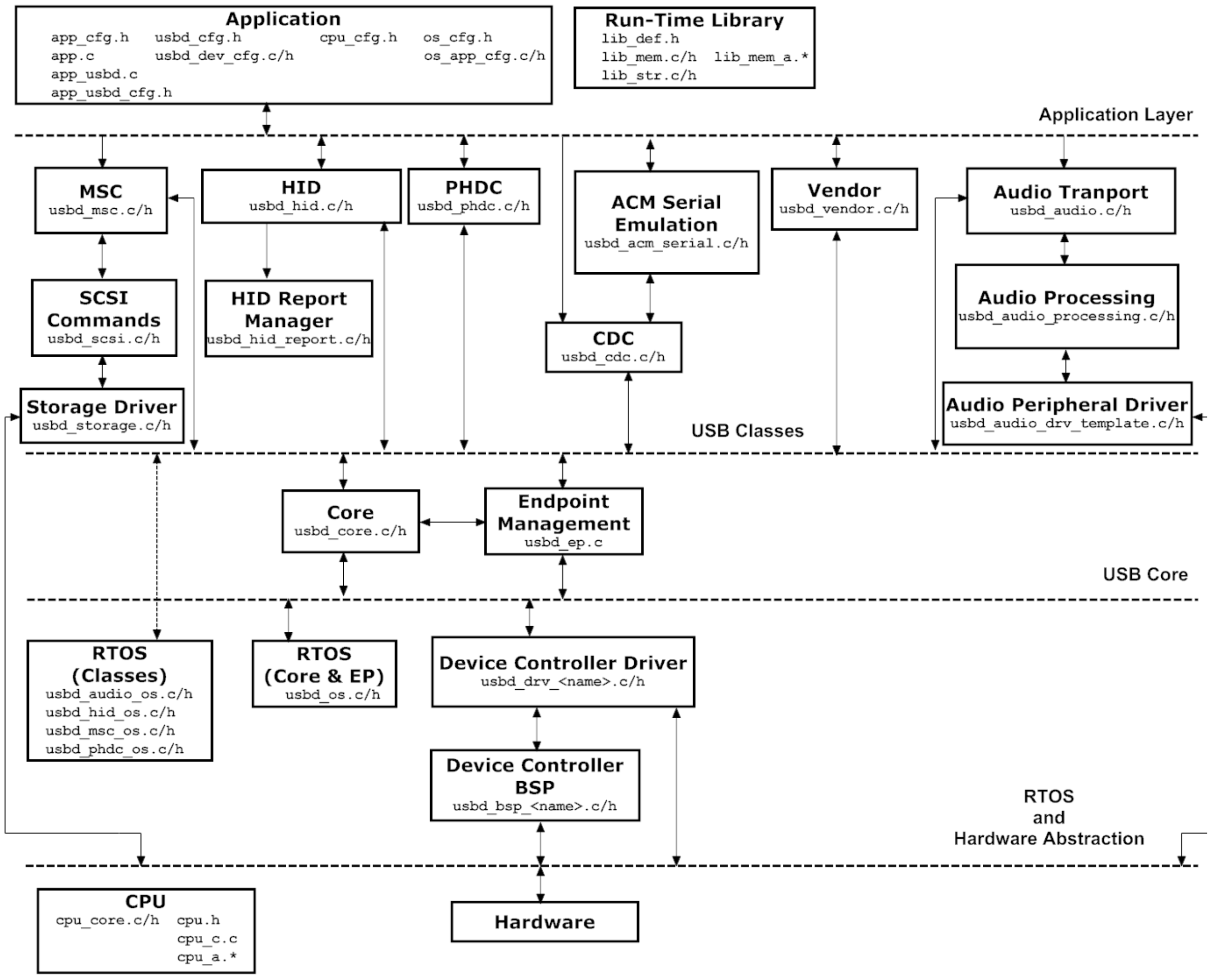


Figure - µC/USB-Device Architecture Block Diagram

Porting uCUSB-Device to your RTOS

Application

Your application layer needs to provide configuration information to µC/USB-Device in the form of several C files: `app_cfg.h`, `app_usbd_cfg.h`, `usbd_cfg.h`, `usbd_dev_cfg.c`, `usbd_dev_cfg.h` and optionnaly `usbd_audio_dev_cfg.c` and `usbd_audio_dev_cfg.h`:

- `app_cfg.h` is an application-specific configuration file. It contains #defines to specify task priorities and the stack size of each of the task within the application and the task(s) required by µC/USB-Device.

- `app_usbd_cfg.h` is a configuration file for the sample µC/USB-Device applications. It contains #defines to enable or disable each sample application and set various parameters for the different applications. For example, set the waveform used in the audio application, enable the mouse application for the HID class or set the type of Vendor sample application.

- Configuration data in `usbd_cfg.h` consists of specifying the number of devices supported in the stack, the maximum number of configurations, the maximum number of interfaces and alternate interfaces, maximum number of opened endpoints per device, class-specific configuration parameters and more. In all, there are approximately 20 #defines to set.

- `usbd_dev_cfg.c/.h` consists of device-specific configuration requirements such as vendor ID, product ID, device release number and its respective strings. It also contains device controller specific configurations such as base address, dedicated memory base address and size, and endpoint management table.

- `usbd_audio_dev_cfg.c/.h`, are audio-specific configuration files and are only needed if the audio class is used. These files defines the audio device topography, allowing the user to build the exact type of audio device needed. Refer to the Audio Topology Configuration page for more details.

Refer to the Configuration page for more information on how to configure µC/USB-Device.

Libraries

Given that µC/USB-Device is designed to be used in safety critical applications, some of the "standard" library functions such as `strcpy()`, `memset()`, etc. have been rewritten to conform to the same quality standards as the rest of the USB device stack. All these standard functions are part of a separate Micrium product called µC/LIB. µC/USB-Device depends on this product. In addition, some data objects in USB controller drivers are created at run-time which implies the use of memory allocation from the heap function `Mem_HeapAlloc()`.

USB Class Layer

Your application will interface with µC/USB-Device using the class layer API. In this layer, four classes defined by the USB-IF are implemented. In case you need to implement a vendor-specific class, a fifth class, the "vendor" class, is available. This class provides functions for simple communication via endpoints. The classes that µC/USB-Device currently supports are the following:

- Audio Class
- Communication Device Class (CDC)
- CDC Abstract Control Model (ACM) subclass
- CDC Ethernet Emulation Model (EEM) subclass
- Human Interface Device Class (HID)
- Mass Storage Class (MSC)
- Personal Healthcare Device Class (PHDC)
- Vendor Class

You can also create other classes defined by the USB-IF. Refer to the USB Classes page for more information on how a USB class interacts with the core layer.

USB Core Layer

USB core layer is responsible for creating and maintaining the logical structure of a USB device. The core layer manages the USB configurations, interfaces, alternate interfaces and allocation of endpoints based on the application or USB classes requirements and the USB controller endpoints available. Standard requests, bus events (reset, suspend, connect and disconnect) and enumeration process are also handled by the Core layer.

Endpoint Management Layer

The endpoint management layer is responsible for sending and receiving data using endpoints. Control, interrupt, bulk and isochronous transfers are implemented in this layer. This layer provides synchronous API for control, bulk and interrupt I/O operations and asynchronous API for bulk, interrupt and isochronous I/O operations.

Real-Time Operating System (RTOS) Abstraction Layer

µC/USB-Device assumes the presence of an RTOS, and an RTOS abstraction layer allows µC/USB-Device to be independent of a specific RTOS. The RTOS abstraction layer is composed of several RTOS ports, a core layer port and some class layer ports.

Core Layer Port

At the very least, the RTOS for the core layer:

- Creates at least one task for the core operation and one optional task for the debug trace feature.

- Provides semaphore management (or the equivalent). Semaphores are used to signal completion or error in synchronous I/O operations and trace events.

- Provides queue management for I/O and bus events.

µC/USB-Device is provided with ports for µC/OS-II and µC/OS-III. If a different RTOS is used, you can use the files for µC/OS-II or µC/OS-III as a template to interface to the RTOS of your choice. For more information on how to port µC/USB-Device to an RTOS, see the Porting uC-USB-Device to your RTOS page.

Class Layer Ports

Some USB classes require an RTOS port (i.e. Audio, HID, MSC and PHDC). Refer to Table - References to Port a Module to an RTOS in the *Porting Modules to an RTOS* page for a list of sections containing more information on the RTOS port of each of these classes.

Hardware Abstraction Layer

µC/USB-Device works with nearly any USB device controller. This layer handles the specifics of the hardware, e.g., how to initialize the device, how to open and configure endpoints, how to start reception and transmission of USB packets, how to read and write USB packets and how to report USB events to the core, among others. The USB device driver controller functions are encapsulated and implemented in the `usbd_drv_<controller>.c` file.

In order to have independent configuration for clock gating, interrupt controller and general purpose I/O, a USB device controller driver needs an additional file. This file is called a Board Support Package (BSP). The name of this file is `usbd_bsp_<controller>.c`. This file contains all the details that are closely related to the hardware on which the product is used. This file also defines the *endpoints information table.* This table is used by the core layer to allocate endpoints according to the hardware capabilities.

CPU Layer

µC/USB-Device can work with either an 8, 16, 32 or even 64-bit CPU, but it must have information about the CPU used. The CPU layer defines such information as the C data type corresponding to 16-bit and 32-bit variables, whether the CPU has little or big endian memory organization, and how interrupts are disabled and enabled on the CPU.

CPU-specific files are found in the `\uC-CPU` directory and are used to adapt µC/USB-Device to a different CPU.

Task Model

µC/USB-Device requires two tasks: One core task and one optional task for tracing debug events. The core task has three main responsibilities:

- Process USB bus events: Bus events such as reset, suspend, connect and disconnect are processed by the core task. Based on the type of bus event, the core task sets the state of the device.
- Process USB requests: USB requests are sent by the host using the default control endpoint. The core task processes all USB requests. Some requests are handled by the USB class driver, for those requests the core calls the class-specific request handler.
- Process I/O asynchronous transfers: Asynchronous I/O transfers are handled by the core. Under completion, the core task invokes the respective callback for the transfer.

Figure - µC/USB-Device Task Model in the *Task Model* page shows a simplified task model of µC/USB-Device along with application tasks.

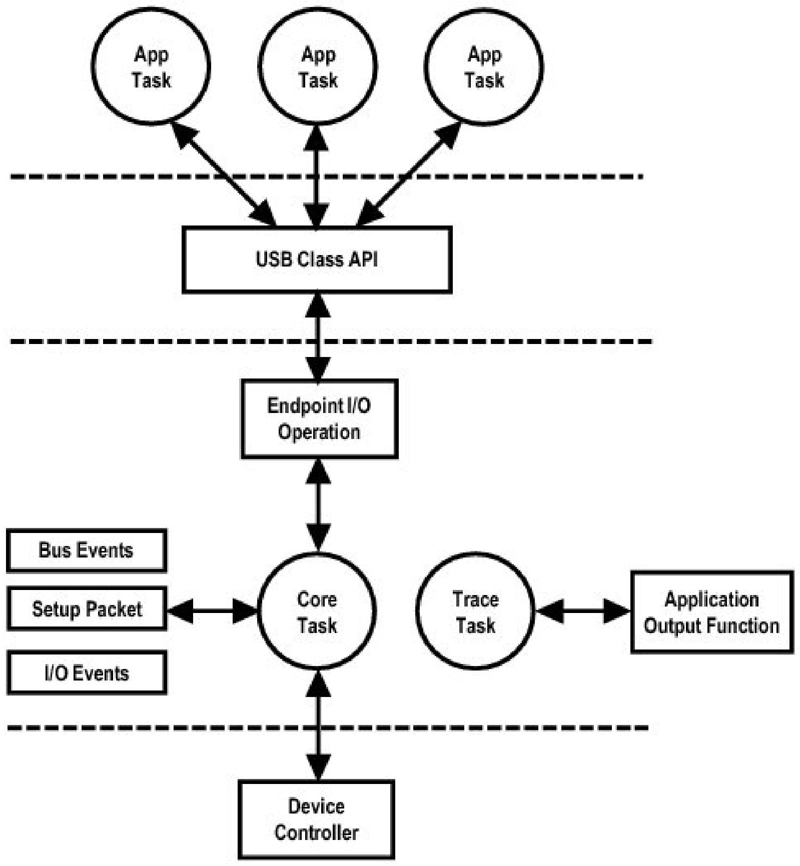


Figure - µC/USB-Device Task Model

Sending and Receiving Data

Figure - Sending and Receiving a Packet in the *Task Model* page shows a simplified task model of µC/USB-Device when data is transmitted and received through the USB device controller. With µC/USB-Device, data can be sent asynchronously or synchronously. In a synchronous operation, the application blocks execution until the transfer operation completes, or an error or a time-out has occurred. In an asynchronous operation, the application does not block and several transfers on a same endpoint can be queued, if the driver allows it. The core task notifies the application when the transfer operation has completed through a callback function.

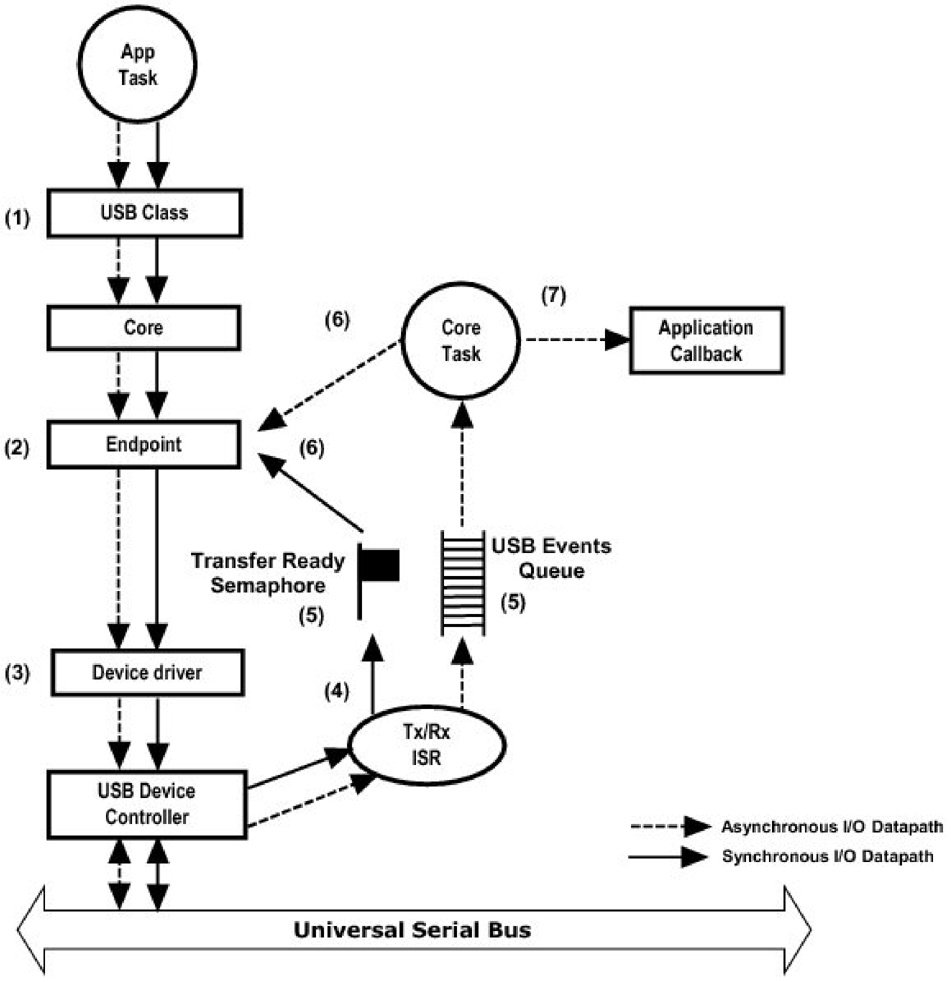


Figure - Sending and Receiving a Packet

(1) An application task that wants to receive or send data, interfaces with µC/USB-Device through the USB classes API. The USB classes API interfaces with the core API, which in turn, interfaces with the endpoint layer API.

(2) The endpoint layer API prepares the data depending on the endpoint characteristics.

(3) When the USB device controller is ready, the driver prepares the transmission or the reception.

(4) Once the transfer has completed, the USB device controller generates an interrupt. Depending on the operation (transmission or reception) the USB device controller’s

driver ISR invokes the transmit complete or receive complete function from the core.

(5) If the operation is synchronous, the transmit or receive complete function will signal the transfer ready counting semaphore. If the operation is asynchronous, the transmit or receive complete function will put a message in the USB core event queue for deferred processing by the USB core task.

(6) If the operation is synchronous, the endpoint layer will wait on the counting semaphore. The operation repeats steps 2 to 5 until the whole transfer has completed.

(7) The core task waits on events to be put in the core event queue. In asynchronous transfers, the core task will call the endpoint layer until the operation is completed.

(8) In asynchronous mode, after the transfer has completed, the core task will call the application completion callback to notify the end of the I/O operation.

Processing Setup Packets (USB Requests)

USB requests are processed by the core task. Figure - Processing Setup Packets (USB Requests) in the *Task Model* page shows a simplified task diagram of a USB request processing.

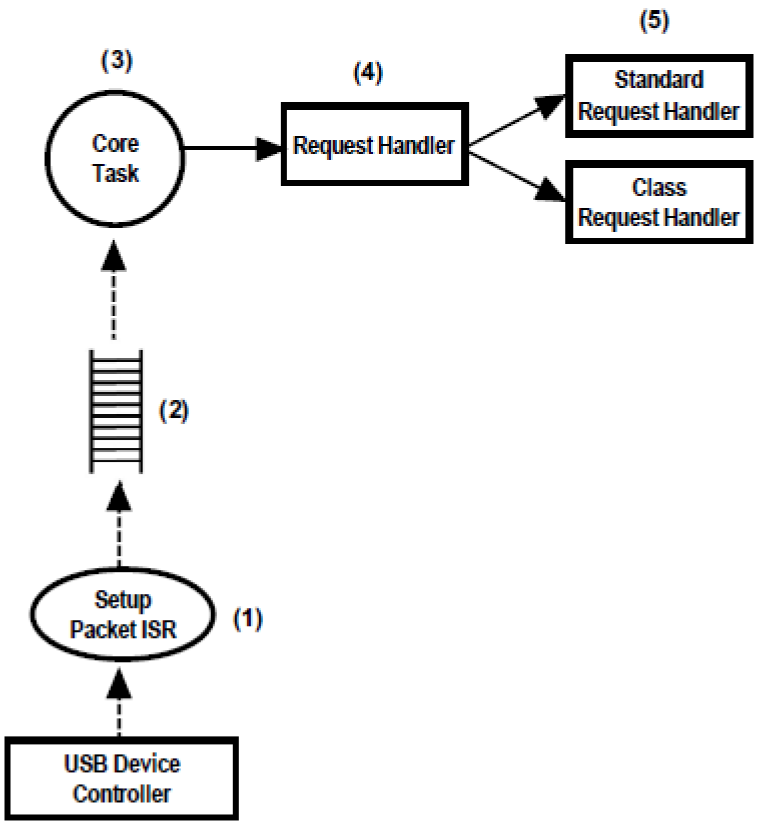


Figure - Processing Setup Packets (USB Requests)

(1) USB requests are sent using control transfers. During the setup stage of the control transfer, the USB device controller generates an interrupt to notify the driver that a new setup packet has arrived.

(2) The USB device controller driver ISR notifies the core by pushing the event in the core event queue.

(3) The core task receives the message from the queue, and starts parsing the USB request by calling the request handler.

(4) The request handler analyzes the request type and determines if the request is a standard, vendor or class specific request.

(5) Standard requests are processed by the core layer. Vendor and class specific requests are processed by the class driver, in the class layer.

Processing Bus Events

USB bus events such as reset, resume, connect, disconnect, and suspend are processed in the same way as the USB requests. The core processes the USB bus events to modify and update the current state of the device. The application can be notified of any bus event by registering a callback function via the Bus Event callback structure. Figure - Processing Bus Events in the *Task Model* page shows a simplified diagram of the USB events process.

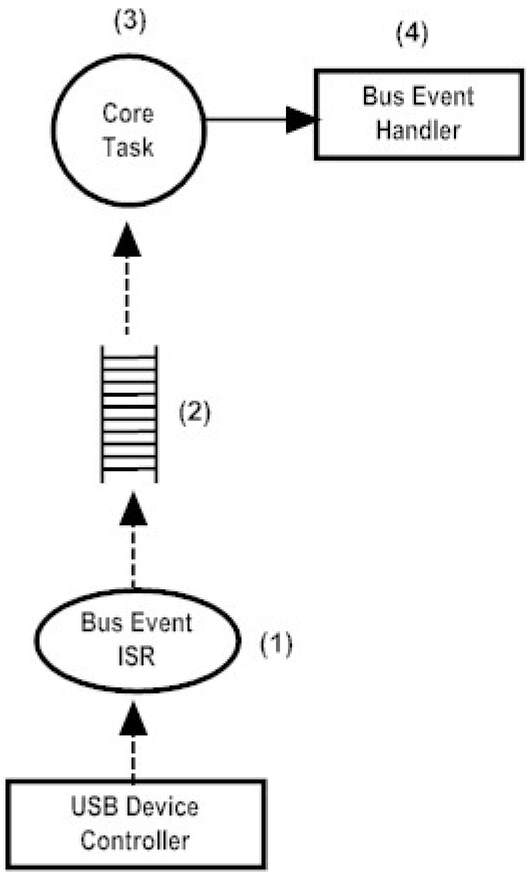


Figure - Processing Bus Events

(1) The USB device controller will generate an interrupt when a bus state change (reset, suspend, etc.) occurs.

(2) The USB device controller driver ISR notifies the core by pushing the event in the core

event queue.

(3) The core task receives the message from the queue, and starts parsing the Bus Event by calling the bus event handler.

(4) The bus event handler analyzes the event type and takes the appropriate action (reset, suspend or resume the device, call the notification callbacks if any, etc.).

Bus Event Callback Structure

This structure allows the application to register callback functions that will be called whenever a bus event happens, allowing the user to implement any application-specific action depending on the bus event. The address of this structure must be passed as a parameter to `USBD_DevAdd()`. See the Modify USB Application Initialization Code section for more details on the initialization of a device or the Application Callback Functions API reference for more details on these callback functions. The Table - Bus Event Callbacks Execution in the *Task Model* page gives details about when a callback is executed based on the device states detailed by *Figure 9-1 in the USB 2.0 Specification*.

Bus Event	Device State Transition	Associated Callback
Reset	From any state to *Default*.	Reset()
Suspend	From any state to *Suspended*.	Suspend()
Resume	From *Suspended* to previous state.	Resume()
Configuration Set	From *Addressed* to *Configured*.	CfgSet()
Configuration Clear	From *Configured* to *Addressed*.	CfgClr()
Connection of the device	From disconnected to connected.	Conn()
Disconnection of the device	From connected to disconnected.	Disconn()

Table - Bus Event Callbacks Execution

Listing - Sample Bus Event Callback Structure in the *Task Model* page shows a sample bus event callback structure.

```
static  void  App_USBD_EventReset  (CPU_INT08U   dev_nbr);

static  void  App_USBD_EventSuspend(CPU_INT08U   dev_nbr);

static  void  App_USBD_EventResume (CPU_INT08U   dev_nbr);

static  void  App_USBD_EventCfgSet (CPU_INT08U   dev_nbr,
                                    CPU_INT08U   cfg_val);

static  void  App_USBD_EventCfgClr (CPU_INT08U   dev_nbr,
                                    CPU_INT08U   cfg_val);

static  void  App_USBD_EventConn   (CPU_INT08U   dev_nbr);

static  void  App_USBD_EventDisconn(CPU_INT08U   dev_nbr);

static  USBD_BUS_FNCTS  App_USBD_BusFncts = {
    App_USBD_EventReset,
    App_USBD_EventSuspend,
    App_USBD_EventResume,
    App_USBD_EventCfgSet,
    App_USBD_EventCfgClr,
    App_USBD_EventConn,
    App_USBD_EventDisconn
};
```

Listing - Sample Bus Event Callback Structure

Processing Debug Events

µC/USB-Device contains an optional debug and trace feature. Debug events are managed in the core layer using a dedicated task. Figure - Processing USB Debug Events in the *Task Model* page shows how the core manages debug events.

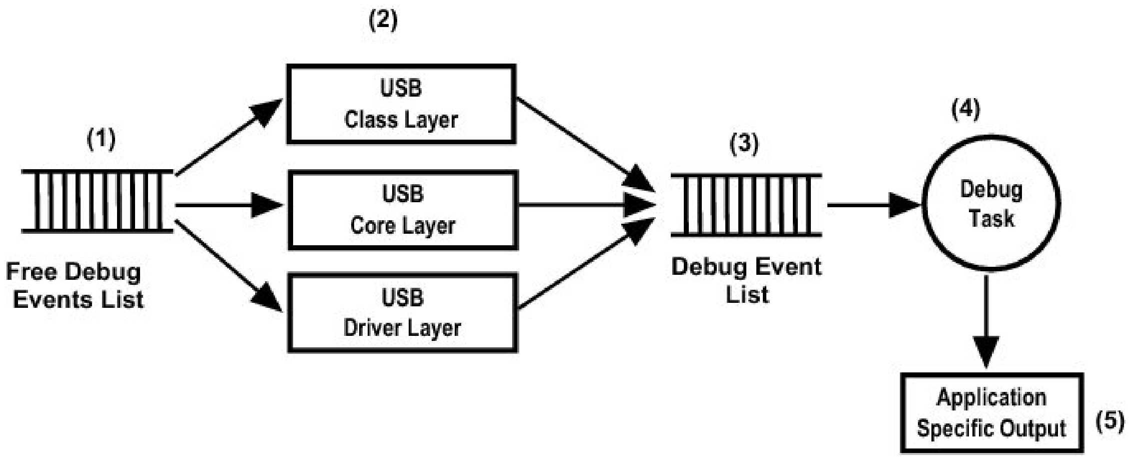


Figure - Processing USB Debug Events

(1) The debug and trace module in the core contains a free list of USB debug events. The debug events objects contain useful information such as the endpoint number, interface number or the layer that generates the events.

(2) Multiple µC/USB-Device layers take available debug event objects to trace useful information about different USB related events.

(3) Trace and debug information events are pushed in the `debug event list`.

(4) The debug task is dormant until a new debug event is available in the debug event list. The debug task will parse the information contained in the debug event object and it will output it in a human readable format using the application specific output trace function `USBD_Trace`.

(5) The application specific output function outputs the debug trace information.

For more information on the debug and trace module, see the Debug and Trace page.

Configuration

Prior to usage, µC/USB-Device must be properly configured. There are three groups of configuration parameters:

- Static stack configuration
- Application specific configuration
- Device and device controller driver configuration

This chapter explains how to setup all these groups of configuration. The last section of this chapter also provides examples of configuration following examples of typical usage.

Static Stack Configuration

μC/USB-Device is configurable at compile time via approximately 20 `#defines` in the application’s copy of `usbd_cfg.h`. μC/USB-Device uses `#defines` when possible, because they allow code and data sizes to be scaled at compile time based on enabled features and the configured number of USB objects. This allows the Read-Only Memory (ROM) and Random-Access Memory (RAM) footprints of μC/USB-Device to be adjusted based on application requirements.

It is recommended that the configuration process begins with the default configuration values which in the next sections will be shown in **bold**.

The sections in this chapter are organized following the order in μC/USB-Device’s template configuration file, `usbd_cfg.h`.

Core Configuration

Generic Configuration

Constant	Description	Possible values
`USBD_CFG_OPTIMIZE_SPD`	Optimizes for either better performance or for smallest code size. Enabling this define will optimize µC/USB-Device code for better performance and disabling this define will lead to smaller code size.	**`DEF_ENABLED`** or `DEF_DISABLED`
`USBD_CFG_MAX_NBR_DEV`	Configures the maximum number of devices. This value should be set to the number of device controllers used on your platform.	Default value is **1**.
`USBD_CFG_BUF_ALIGN_OCTETS`	Configures the alignment in octets that internal stack's buffer needs. This value should be set in function of your platform/hardware requirements. If your platform does not require buffer alignment, this should be set to the size of a CPU word (`sizeof(CPU_ALIGN)`).	Typically 1, 2, 4 or 8. Default value is **sizeof(CPU_ALIGN)** .
`USBD_ERR_CFG_ARG_CHK_EXT_EN`	Allows code to be generated to check arguments for functions that can be called by the user and, for functions which are internal but receive arguments from an API that the user can call.	**`DEF_ENABLED`** or `DEF_DISABLED`
`USBD_CFG_MS_OS_DESC_EN`	Enables or disables support of Microsoft OS descriptors. Enabling this feature will cause the device to respond to Microsoft OS string descriptor requests and Microsoft OS specific descriptors. For more information on Microsoft OS descriptors, refer to the *Microsoft Hardware Dev Center.*	`DEF_ENABLED` or **`DEF_DISABLED`**

Table - Generic Configuration Constants

USB Device Configuration

Constant	Description	Possible Values
`USBD_CFG_MAX_NBR_CFG`	Sets the maximum number of USB configurations used by your device. Keep in mind that if you use a high-speed USB device controller, you will need at least two USB configurations, one for low and full-speed and another for high-speed. Refer to the *Universal Serial Bus specification, Revision 2.0, section 9.2.3* for more details on USB configuration.	From 1 (low- or full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_CFG_EP_ISOC_EN`	Selected portions of C/USB-Device code required only for isochronous transfers may be disabled to reduce the code size by configuring `USBD_CFG_EP_ISOC_EN`. This define should be set to `DEF_DISABLED` if isochronous transfers are not required, to save space.	**`DEF_ENABLED`** or `DEF_DISABLED`
`USBD_CFG_HS_EN`	Selected portions of C/USB-Device code required only for high-speed operation may be disabled to reduce the code size by configuring `USBD_CFG_HS_EN`. This define should be set to `DEF_ENABLED` if the USB device controller supports high-speed, or to `DEF_DISABLED` otherwise.	**`DEF_ENABLED`** or `DEF_DISABLED`
`USBD_CFG_CTRL_REQ_TIMEOUT_mS`	Sets the timeout in milliseconds for the Data and the Status phases of a control transfer. This timeout prevent from a deadlock situation during a control transfer processing by the core layer. Thus a value of 0, meaning wait forever, is not allowed.	From 1 to 65535. Default value is **5000**.

Table - Device Configuration Constants

Interface Configuration

Constant	Description	Possible Values
`USBD_CFG_MAX_NBR_IF`	Configures the maximum number of interfaces available. This value should at least be equal to `USBD_CFG_MAX_NBR_CFG` and greatly depends on the USB class(es) used. It represents the total number of interfaces usable for all configurations of your device. Each class instance requires at least one interface, while CDC-ACM requires two.Refer to the *Universal Serial Bus specification, Revision 2.0, section 9.2.3* for more details on USB interfaces.	From 1 to 254. Default value is **2**.
`USBD_CFG_MAX_NBR_IF_ALT`	Defines the maximum number of alternate interfaces (alternate settings) available. This value should at least be equal to `USBD_CFG_MAX_NBR_IF` and represents the total number of alternate interfaces usable by all interfaces of your device. Refer to the *Universal Serial Bus specification, Revision 2.0, section 9.2.3* for more details on alternate settings.	From 1 to 254. Default value is **2**.
`USBD_CFG_MAX_NBR_IF_GRP`	Defines the maximum number of interface groups or associations available. For the moment, Micrium offers only one USB class (CDC-ACM) that requires interface groups. Refer to the Interface Association Descriptors USB Engineering Change Notice for more details about interface associations.	From 0 to 254. Default value is **0** (should be equal to the number of instances of CDC-ACM).
`USBD_CFG_MAX_NBR_EP_DESC`	Defines the maximum number of endpoint descriptors available. This value greatly depends on the USB class(es) used. For information on how many endpoints are needed for each class, refer to the class specific chapter. Keep in mind that control endpoints do not need any endpoint descriptors.	From 0 to 254. Default value is **2**.
`USBD_CFG_MAX_NBR_EP_OPEN`	Configures the maximum number of opened endpoints per device. If you use more than one device, set this value to the worst case. This value greatly depends on the USB class(es) used. For information on how many endpoints are needed for each class, refer to the class specific chapter.	From 2 to 32. Default value is **4** (2 control plus 2 other endpoints).
`USBD_CFG_MAX_NBR_URB_EXTRA`	Defines the number of additional URBs that are used for asynchronous transfers only. Since these URBs are shared between every endpoint, if one endpoint uses them all, other endpoints will not be able to queue any transfer, although it is guaranteed that every endpoint always has one URB still available, to ensure that a transfer can be done at any time.	From 0 to (65535 - `USBD_CFG_MAX_NBR_EP_OPEN` - `USBD_CORE_EVENT_URB_NBR_TOTAL`). Default value is **0**.

Table - Interface Configuration Constants

String Configuration

Constant	Description	Possible Values
`USBD_CFG_MAX_NBR_STR`	Configures the maximum number of string descriptors supported. This value can be increased if, for example, you plan to add interface specific strings.	From 1 to 254. Default value is **3** (1 descriptor for Manufacturer string, Product string and Serial Number string).

Table - String Configuration Constants

Debug Configuration

Configurations in this section only need to be set if you use the core debugging service. For more information on that service, see the Debug and Trace page.

Constant	Description	Possible Values
`USBD_CFG_DBG_TRACE_EN`	Enables or disables the core debug trace engine.	`DEF_ENABLED` or `DEF_DISABLED`
`USBD_CFG_DBG_TRACE_NBR_EVENTS`	Defines the maximum number of debug trace events that can be queued by the core debug trace engine. This configuration constant has no effect and will not allocate any memory if `USBD_CFG_DBG_TRACE_EN` is set to `DEF_DISABLED`.	From 1 to 65535. Default value is **10**.

Table - Debug Configuration Constants

Classes Configuration

Audio Class Configuration

Constant	Description	Possible Values
`USBD_AUDIO_CFG_PLAYBACK_EN`	Enables or disables playback.	**`DEF_ENABLED`** or `DEF_DISABLED`
`USBD_AUDIO_CFG_RECORD_EN`	Enables or disables record. `USBD_AUDIO_CFG_PLAYBACK_EN` and `USBD_AUDIO_CFG_RECORD_EN` can be `DEF_DISABLED` at the same time. In that case, only the AudioControl interface is active. No AudioStreaming interface can be defined. It may be useful to configure an audio device which does not interact with the host through USB for audio streaming.	**`DEF_ENABLED`** or `DEF_DISABLED`
`USBD_AUDIO_CFG_FU_MAX_CTRL`	Enables all Feature Unit controls or disables all optional controls. When disabled, only the mute and volume controls are kept.	`DEF_ENABLED` or **`DEF_DISABLED`**
`USBD_AUDIO_CFG_MAX_NBR_AIC`	Configures the maximum number of class instances. Unless you plan on having multiple configurations or interfaces using different class instances, this can be set to 1.	From 1 to 254. Default value is **1** .
`USBD_AUDIO_CFG_MAX_NBR_CFG`	Configures the maximum number of configurations in which audio class is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed.	From 1 (full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_AUDIO_CFG_MAX_NBR_IT`	Configures the maximum number of input terminals.	From 1 to 255. Default value is **2**.
`USBD_AUDIO_CFG_MAX_NBR_OT`	Configures the maximum number of output terminals.	From 1 to 255. Default value is **2** .
`USBD_AUDIO_CFG_MAX_NBR_FU`	Configures the maximum number of feature units.	From 1 to 255. Default value is **2** .
`USBD_AUDIO_CFG_MAX_NBR_MU`	Configures the maximum number of mixer units. A Mixer Unit is optional.	From 0 to 255. Default value is **0** .
`USBD_AUDIO_CFG_MAX_NBR_SU`	Configures the maximum number of selector units. A Selector Unit is optional.	From 0 to 255. Default value is **0** .
`USBD_AUDIO_CFG_MAX_NBR_AS_IF_PLAYBACK`	Configures the maximum number of playback AudioStreaming interfaces per class instance.	From 1 to 255. Default value is **1** .
`USBD_AUDIO_CFG_MAX_NBR_AS_IF_RECORD`	Configures the maximum number of record AudioStreaming interfaces per class instance.	From 1 to 255. Default value is **1** .

`USBD_AUDIO_CFG_MAX_NBR_IF_ALT`	Configures the maximum number of operational alternate setting interfaces per AudioStreaming interface.	From 1 to 255. Default value is **2** .
`USBD_AUDIO_CFG_CLASS_REQ_MAX_LEN`	Configures the maximum class-specific request playload length in bytes. Among all class-specific requests supported by Audio 1.0 class, the Graphic Equalizer control of the Feature Unit use the longest payload size for the SET_CUR request. The payload for the Graphic Equalizer control can take up to 34 bytes depending of the number of frequency bands present. If the Graphical Equalizer control is not used by any feature unit, this constant can be set to 4. Refer to audio 1.0 specification, Table 5-27 for more details about Graphic Equalizer control.	From 1 to 34. Default value is **4** .
`USBD_AUDIO_CFG_BUF_ALIGN_OCTETS`	Configures the alignment in octets that audio buffers allocated for each AudioStreaming interface will use. The alignment is dependent of the peripheral used to move data between the memory and the audio peripheral. Note that this buffer alignment should be a multiple of the internal stack's buffer alignment set with the constant `USBD_CFG_BUF_ALIGN_OCTETS` as the audio buffers are passed to the USB device controller that can also have its alignment requirement. If your platform does not require buffer alignment, this should be set to `USBD_AUDIO_CFG_BUF_ALIGN_OCTETS`. If the CPU cache is used with the audio buffers, `USBD_AUDIO_CFG_BUF_ALIGN_OCTETS` should also take into account the cache line size requirement. To sum up, the value of `USBD_AUDIO_CFG_BUF_ALIGN_OCTETS` is influenced by: • Audio peripheral alignment requirement • USB device controller alignment requirement • Cache alignment requirement If all above requirements must be taken into account, `USBD_AUDIO_CFG_BUF_ALIGN_OCTETS` will be the worst case among all alignment requirements.	Typically 1, 2, 4 or 8. Default value is **`USBD_CFG_BUF_ALIGN_OCTETS`** .

`USBD_AUDIO_CFG_PLAYBACK_FEEDBACK_EN`	Enables or disables the playback feedback support. If an isochronous OUT endpoint using the asynchronous synchronization is associated to an AudioStreaming interface, you need to set `DEF_ENABLED` to enable the feedback support. Refer to section Playback Feedback Correction for more details about the audio feedback.	`DEF_ENABLED` or **`DEF_DISABLED`**
`USBD_AUDIO_CFG_PLAYBACK_CORR_EN`	Enables or disables built-in playback stream correction.	`DEF_ENABLED` or **`DEF_DISABLED`**
`USBD_AUDIO_CFG_RECORD_CORR_EN`	Enables or disables built-in record stream correction.	`DEF_ENABLED` or **`DEF_DISABLED`**
`USBD_AUDIO_CFG_STAT_EN`	Enables or disables audio statistics for playback and record.	`DEF_ENABLED` or **`DEF_DISABLED`**

Table - Audio Class Configuration Constants

Communication Device Class Configuration

Some constants are available to customize the CDC base class. These constants are located in the USB device configuration file, `usbd_cfg.h`. Table - CDC Class Configuration Constants in the *CDC Configuration* page shows their description.

Constant	Description	Possible Values
`USBD_CDC_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances. Each associated subclass also defines a maximum number of subclass instances. The sum of all the maximum numbers of subclass instances must *not* be greater than `USBD_CDC_CFG_MAX_NBR_DEV`.	From 1 to 254. Default value is **1**.
`USBD_CDC_CFG_MAX_NBR_CFG`	Configures the maximum number of configurations in which CDC class is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed.	From 1 (low- and full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_CDC_CFG_MAX_NBR_DATA_IF`	Configures the maximum number of Data interfaces.	From 1 to 254. The default value is **1**.

Table - CDC Class Configuration Constants

CDC Abstract Control Model Serial Class Configuration

Table - ACM Serial Emulation Subclass Configuration Constants in the *ACM Subclass* page shows the constant available to customize the ACM serial emulation subclass. This constant is located in the USB device configuration file, `usbd_cfg.h`.

Constant	Description	Possible Values
`USBD_ACM_SERIAL_CFG_MAX_NBR_DEV`	Configures the maximum number of subclass instances. The constant value cannot be greater than `USBD_CDC_CFG_MAX_NBR_DEV`. Unless you plan on having multiple configurations or interfaces using different class instances, this can be set to the default value.	From 1 to `USBD_CDC_CFG_MAX_NBR_DEV`. Default value is **1**.

Table - ACM Serial Emulation Subclass Configuration Constants

Communication Device Class Ethernet Emulation Model Subclass Configuration

There are various configuration constants necessary to customize the CDC EEM subclass. These constants are located in the `usbd_cfg`.h file. Table - CDC EEM Configuration Constants in the *CDC EEM Subclass Configuration* page shows a description of each constant.

Constant	Description	Possible Values
`USBD_CDC_EEM_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances. Unless you plan having multiple configuration or interfaces using different class instances, this should be set to **1**.	From 1 to 254. Default value is **1** .
`USBD_CDC_EEM_CFG_MAX_NBR_CFG`	Configures the maximum number of configuration in which CDC EEM is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed.	From 1 (full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_CDC_EEM_CFG_RX_BUF_LEN`	Configures the length, in octets, of the buffer(s) used to receive the data from the host. This buffer must ideally be a multiple of the max packet size of the endpoint. However, most of the time this can be set to the Ethernet Maximum Transmit Unit (MTU -> 1518) + 2 for the CDC EEM header for better performances.	64 or more. Multiple of maximum packet size if below (MTU + 2). Default value is **1520**.
`USBD_CDC_EEM_CFG_ECHO_BUF_LEN`	Configures the length, in octets, of the echo buffer used to transmit an echo response command upon reception of an echo command from the host. Size of this buffer depends on the largest possible echo data that can be sent by the host.	Higher than 2. Default value is **64.**
`USBD_CDC_EEM_CFG_RX_BUF_QTY_PER_DEV` **(optional)**	Configures the quantity of receive buffers to be used to receive data from the host. It is not mandatory to set the value in your `usbd_cfg.h` file. Before setting this value to something higher than 1, you MUST ensure that you USB device driver supports URB queuing. You must also correctly configure the constant `USBD_CFG_MAX_NBR_URB_EXTRA`. Increasing this value will improve the data reception performances by providing multiple buffering mechanism.	1 or more. Default value is **1** .

Table - CDC EEM Configuration Constants

Human Interface Device Class Configuration

Constant	Description	Possible Values
`USBD_HID_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances. Unless you plan on having multiple configurations or interfaces using different class instances, this can be set to the default value.	From 1 to 254. Default value is **1**.
`USBD_HID_CFG_MAX_NBR_CFG`	Configures the maximum number of configurations in which HID class is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed.	From 1 (low- and full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_HID_CFG_MAX_NBR_REPORT_ID`	Configures the maximum number of report IDs allowed in a report. The value should be set properly to accommodate the number of report ID to be used in the report.	From 1 to 65535. Default value is **1**.
`USBD_HID_CFG_MAX_NBR_REPORT_PUSHPOP`	Configures the maximum number of Push and Pop items used in a report. If the constant is set to **0**, no Push and Pop items are present in the report.	From 0 to 254. Default value is **0**.

Table - HID Class Configuration Constants

The HID class uses an internal task to manage periodic input reports. The task priority and stack size shown in Table - HID Internal Task's Configuration Constants in the *HID Class Configuration* page are defined in the application configuration file, `app_cfg.h`. Refer to the HID Periodic Input Reports Task page for more details about the HID internal task.

Constant	Description	Possible Values
`USBD_HID_OS_CFG_TMR_TASK_PRIO`	Configures the priority of the HID periodic input reports task.	From the lowest to the highest priority supported by the OS used.
`USBD_HID_OS_CFG_TMR_TASK_STK_SIZE`	Configures the stack size of the HID periodic input reports task. The required size of the stack can greatly vary depending on the OS used, the CPU architecture, the type of application, etc. Refer to the documentation of the OS for more details about tasks and stack size calculation.	From the minimal to the maximal stack size supported by the OS used.

Table - HID Internal Task's Configuration Constants

Mass Storage Class Configuration

There are various configuration constants necessary to customize the MSC device. These constants are located in the usbd_cfg.h file. Table - MSC Configuration Constants in the *MSC Configuration* page shows a description of each constant.

Constant	Description	Possible Values
`USBD_MSC_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances. Unless you plan having multiple configuration or interfaces using different class instances, this should be set to **1**.	From 1 to 254. Default value is **1**.
`USBD_MSC_CFG_MAX_NBR_CFG`	Configures the maximum number of configuration in which MSC is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed.	From 1 (low- and full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_MSC_CFG_MAX_LUN`	Configures the maximum number of logical units.	From 1 to 255. Default value is **1**.
`USBD_MSC_CFG_DATA_LEN`	Configures the read/write data length in octets.	Higher than 0. The default value is **2048.**
`USBD_MSC_CFG_FS_REFRESH_TASK_EN`	Enables or disables the use of a task in µC/FS storage layer for removable media insertion/removal detection. If only fixed media such as RAM, NAND are used, this constant should be set to `DEF_DISABLED`. Otherwise, `DEF_ENABLED` should be set.	`DEF_ENABLED` or **`DEF_DISABLED`**
`USBD_MSC_CFG_DEV_POLL_DLY_mS`	Configures the period of the µC/FS storage layer's task. It is expressed in milliseconds. If `USBD_MSC_CFG_FS_REFRESH_TASK_EN` is set to `DEF_DISABLED`, this constant has no effect. A faster period may improve the delay to detect the removable media insertion/removal resulting in a host computer displaying the removable media icon promptly. But the CPU will be interrupted often to check the removable media status. A slower period may result in a certain delay for the host computer to display the removable media icon. But the CPU will spend less time verifying the removable media status.	The default value is **100** ms.

Table - MSC Configuration Constants

Since MSC device relies on a task handler to implement the MSC protocol, this OS-task's priority and stack size constants need to be configured if µC/OS-II or µC/OS-III RTOS is used. Moreover if `USBD_MSC_CFG_FS_REFRESH_TASK_EN` is set to `DEF_ENABLED`, the µC/FS storage layer task's priority and stack size need also to be configured. These constants are summarized in Table - MSC OS-Task Handler Configuration Constants in the *MSC Configuration* page.

Constant	Description	Possible Values
`USBD_MSC_OS_CFG_TASK_PRIO`	MSC task handler's priority level. The priority level must be lower (higher valued) than the start task and core task priorities.	From the lowest to the highest priority supported by the OS used.
`USBD_MSC_OS_CFG_TASK_STK_SIZE`	MSC task handler's stack size. The required size of the stack can greatly vary depending on the OS used, the CPU architecture, the type of application, etc. Refer to the documentation of the OS for more details about tasks and stack size calculation.	From the minimal to the maximal stack size supported by the OS used. Default value is set to **256**.
`USBD_MSC_OS_CFG_REFRESH_TASK_PRIO`	µC/FS storage layer task's priority level. The priority level must be lower (higher valued) than the MSC task.	From the lowest to the highest priority supported by the OS used.
`USBD_MSC_OS_CFG_REFRESH_TASK_STK_SIZE`	µC/FS storage layer task's stack size. The required size of the stack can greatly vary depending on the OS used, the CPU architecture, the type of application, etc. Refer to the documentation of the OS for more details about tasks and stack size calculation.	From the minimal to the maximal stack size supported by the OS used. Default value is set to **256**.

Table - MSC OS-Task Handler Configuration Constants

Personal Healthcare Device Class Configuration

Some constants are available to customize the class. These constants are located in the `usbd_cfg.h` file. Table - Configuration Constants Summary in the *PHDC Configuration* page shows a description of each of them.

Constant	Description	Possible Values
`USBD_PHDC_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances. Unless you plan on having multiple configuration or interfaces using different class instances, this can be set to **1**.	From 1 to 254. Default value is **1**.
`USBD_PHDC_CFG_MAX_NBR_CFG`	Configures the maximum number of configuration in which PHDC is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed. Default value is **2**.	From 1 (low- and full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_PHDC_CFG_DATA_OPAQUE_MAX_LEN`	Maximum length in octets that opaque data can be.	Equal or less than MaxPacketSize - 21. Default value is **43**.
`USBD_PHDC_OS_CFG_SCHED_EN`	If using µC/OS-II or µC/OS-III RTOS port, enable or disable the scheduler feature. You should set it to `DEF_DISABLED` if the device only uses one QoS level to send data, for instance. (See the PHDC RTOS QoS-based scheduler page). If you set `USBD_PHDC_OS_CFG_SCHED_EN` to `DEF_ENABLED` and you use a µC/OS-II or µC/OS-III RTOS port, PHDC will need an internal task for the scheduling operations. There are two application specific configurations that must be set in this case. They should be defined in the `app_cfg.h` file. If you set this constant to `DEF_ENABLED`, you *must* ensure that the scheduler's task has a lower priority (i.e., higher priority value) than any task that can write PHDC data.	**`DEF_ENABLED`** or `DEF_DISABLED`

Table - Configuration Constants Summary

If you set `USBD_PHDC_OS_CFG_SCHED_EN` to `DEF_ENABLED` and you use a µC/OS-II or µC/OS-III RTOS port, PHDC will need an internal task for the scheduling operations. There are two application specific configurations that must be set in this case. They should be defined in the `app_cfg.h` file. Table - Application-Specific Configuration Constants in the *PHDC Configuration* page describes these configurations.

Constant	Description	Possible Values
`USBD_PHDC_OS_CFG_SCHED_TASK_PRIO`	QoS based scheduler's task priority. You *must* ensure that the scheduler's task has a lower priority (i.e. higher priority value) than any task writing PHDC data.	From the lowest to the highest priority supported by the OS used.
`USBD_PHDC_OS_CFG_SCHED_TASK_STK_SIZE`	QoS based scheduler's task stack size. The required size of the stack can greatly vary depending on the OS used, the CPU architecture, the type of application, etc. Refer to the documentation of the OS for more details about tasks and stack size calculation.	From the minimal to the maximal stack size supported by the OS used. Default value is **512**.

Table - Application-Specific Configuration Constants

Vendor Class Configuration

Some constants are available to customize the class. These constants are located in the USB device configuration file, `usbd_cfg.h`. Table - General Configuration Constants Summary in the *Vendor Class Configuration* page shows their description.

Constant	Description	Possible Values
`USBD_VENDOR_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances. Unless you plan on having multiple configurations or interfaces using different class instances, this can be set to **1**.	From 1 to 254. Default value is **1**.
`USBD_VENDOR_CFG_MAX_NBR_CFG`	Configures the maximum number of configuration in which Vendor class is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed.	From 1 (low- and full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_VENDOR_CFG_MAX_NBR_MS_EXT_PROPERTY`	Configures the maximum number of Microsoft extended properties that can be defined per Vendor class instance. For more information on Microsoft OS descriptors and extended properties, refer to the Microsoft *Hardware Dev Center* .	From 1 to 255. Default value is **1**.

Table - General Configuration Constants Summary

Application Specific Configuration

This section defines the configuration constants related to C/USB-Device but that are application-specific. All these configuration constants relate to the RTOS. For many OSs, the C/USB-Device task priorities and stack sizes will need to be explicitly configured for the particular OS (consult the specific OS’s documentation for more information).

These configuration constants should be defined in an application’s `app_cfg.h` file.

Task Priorities

As mentioned in the Task Model section, C/USB-Device needs one core task and one optional debug task for its proper operation. The priority of C/USB-Device’s core task greatly depends on the USB requirements of your application. For some applications, it might be better to set it at a high priority, especially if your application requires a lot of tasks and is CPU intensive. In that case, if the core task has a low priority, it might not be able to process the bus and control requests on time. On the other hand, for some applications, you might want to give the core task a low priority, especially if you plan on using asynchronous communication and if you know you will have quite a lot of code in your callback functions.

The priority of the debug task should generally be low since it is not critical and the task performed can be executed in the background.

For the C/OS-II and C/OS-III RTOS ports, the following macros must be configured within `app_cfg.h`:

- `USBD_OS_CFG_CORE_TASK_PRIO`
- `USBD_OS_CFG_TRACE_TASK_PRIO`

Note: if `USBD_CFG_DBG_TRACE_EN` is set to `DEF_DISABLED`, `USBD_OS_CFG_TRACE_TASK_PRIO` should not be defined.

Task Stack Sizes

For the µC/OS-II and µC/OS-III RTOS ports, the following macros must be configured within `app_cfg.h` to set the internal task stack sizes:

- `USBD_OS_CFG_CORE_TASK_STK_SIZE   1000`
- `USBD_OS_CFG_TRACE_TASK_STK_SIZE  1000`

Note: if `USBD_CFG_DBG_TRACE_EN` is set to `DEF_DISABLED`, `USBD_OS_CFG_TRACE_TASK_STK_SIZE` should not be defined.

The arbitrary stack size of **1000** is a good starting point for most applications.

The only guaranteed method of determining the required task stack sizes is to calculate the maximum stack usage for each task. Obviously, the maximum stack usage for a task is the total stack usage along the task's most-stack-greedy function path. Note that the most-stack-greedy function path is not necessarily the longest or deepest function path.

The easiest and best method for calculating the maximum stack usage for any task/function should be performed statically by the compiler or by a static analysis tool since these can calculate function/task maximum stack usage based on the compiler's actual code generation and optimization settings. So for optimal task stack configuration, we recommend to invest in a task stack calculator tool compatible with your build toolchain.

Device and Device Controller Driver Configuration

In order to finalize the configuration of your device, you need to declare two structures: one will contain information about your device (Vendor ID, Product ID, etc.) and another will contain information useful to the device controller driver. A reference to both of these structures needs to be passed to the `USBD_DevAdd()` function, which allocates a device controller.

For more information on how to modify device and device controller driver configuration, see the Copying and Modifying Template Files page.

Configuration Examples

This section provides examples of configuration for µC/USB-Device stack based on some typical usages. This section will only give examples of static stack configuration, as the application-specific configuration greatly depends on your application. Also, the device configuration is related to your product's context, and the device controller driver configuration depends on the hardware you use.

The examples of typical usage that will be treated are the following:

Simple Full-Speed USB Device

This device uses Micrium's vendor class.

Table - Configuration Example of a Simple Full-Speed USB Device in the *Configuration Examples* page shows the values that should be set for the different configuration constants described earlier if you build a simple full-speed USB device using Micrium's vendor class.

Configuration	Value	Explanation
`USBD_CFG_MAX_NBR_CFG`	1	Since the device is full speed, only one configuration is needed.
`USBD_CFG_MAX_NBR_IF`	1	Since the device only uses the vendor class, only one interface is needed.
`USBD_CFG_MAX_NBR_IF_ALT`	1	No alternate interfaces are needed, but this value must at least be equal to `USBD_CFG_MAX_NBR_IF`.
`USBD_CFG_MAX_NBR_IF_GRP`	0	No interface association needed.
`USBD_CFG_MAX_NBR_EP_DESC`	2 or 4	Two bulk endpoints and two optional interrupt endpoints.
`USBD_CFG_MAX_NBR_EP_OPEN`	4 or 6	Two control endpoints for the device's standard requests. Two bulk endpoints and two optional interrupt endpoints.
`USBD_VENDOR_CFG_MAX_NBR_DEV`	1	Only one instance of vendor class is needed.
`USBD_VENDOR_CFG_MAX_NBR_CFG`	1	Vendor class instance will only be used in one configuration.

Table - Configuration Example of a Simple Full-Speed USB Device

Composite High-Speed USB Device

This device uses Micrium's PHDC and MSC classes.

Table - Configuration Example of a Composite High-Speed USB Device in the *Configuration*

Examples page shows the values that should be set for the different configuration constants described earlier if you build a composite high-speed USB device using Micrium's PHDC and MSC classes. The structure of this device is described in Figure - Composite High-Speed USB Device Structure in the *Configuration Examples* page.

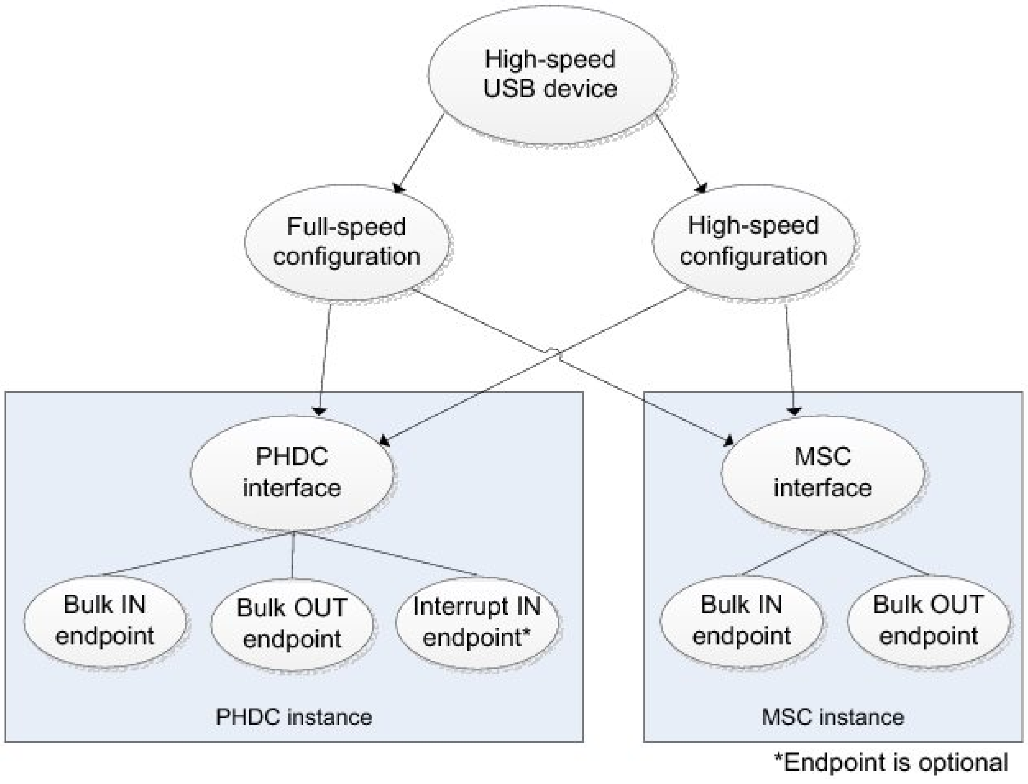


Figure - Composite High-Speed USB Device Structure

Configuration	Value	Explanation
`USBD_CFG_MAX_NBR_CFG`	2	One configuration for full/low-speed and another for high-speed.
`USBD_CFG_MAX_NBR_IF`	4	One interface for PHDC and another for MSC. A different interface for each configuration is also needed.
`USBD_CFG_MAX_NBR_IF_ALT`	4	No alternate interface needed, but this value must at least be equal to `USBD_CFG_MAX_NBR_IF`.
`USBD_CFG_MAX_NBR_IF_GRP`	0	No interface association needed.
`USBD_CFG_MAX_NBR_EP_DESC`	4 or 5	Two bulk endpoints for MSC. Two bulk plus one optional interrupt endpoint for PHDC.
`USBD_CFG_MAX_NBR_EP_OPEN`	6 or 7	Two control endpoints for device's standard requests. Two bulk endpoints for MSC. Two bulk plus 1 optional interrupt endpoint for PHDC.
`USBD_PHDC_CFG_MAX_NBR_DEV`	1	Only one instance of PHDC is needed. It will be shared between all the configurations.
`USBD_PHDC_CFG_MAX_NBR_CFG`	2	PHDC instance can be used in both of device's configurations.
`USBD_MSC_CFG_MAX_NBR_DEV`	1	Only one instance of MSC is needed. It will be shared between all the configurations.
`USBD_MSC_CFG_MAX_NBR_CFG`	2	MSC instance can be used in both of device's configurations.

Table - Configuration Example of a Composite High-Speed USB Device

Complex Composite High-Speed USB Device

This device uses an instance of Micrium's HID class in two different configurations plus a different instance of Micrium's CDC-ACM class in each configuration. This device also uses an instance of Micrium's vendor class in the second configuration.

Table - Configuration Example of a Complex Composite High-Speed USB Device in the *Configuration Examples* page shows the values that should be set for the different configuration constants described earlier if you build a composite high-speed USB device using a single instance of Micrium's HID class in two different configurations plus a different instance of Micrium's CDC-ACM class in each configuration. The device also uses an instance of Micrium's vendor class in its second configuration. See Figure - Complex Composite High-Speed USB Device Structure in the *Configuration Examples* page for a graphical description of this USB device.

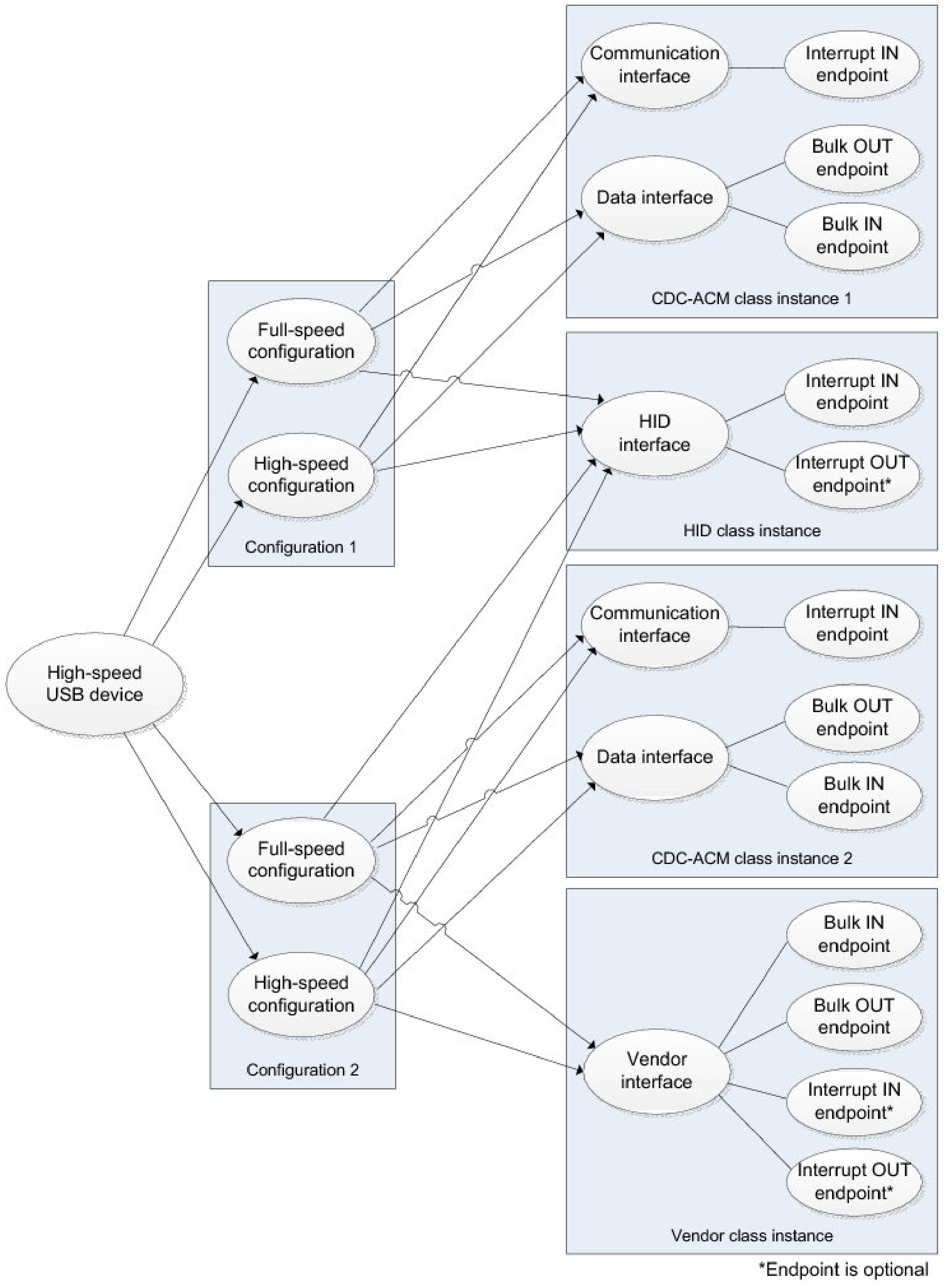


Figure - Complex Composite High-Speed USB Device Structure

Configuration	Value	Explanation
`USBD_CFG_MAX_NBR_CFG`	4	Two configurations for full/low-speed and two others for high-speed.
`USBD_CFG_MAX_NBR_IF`	7	First configuration: - One interface for HID. - Two interfaces for CDC-ACM. Second configuration: - One interface for HID. - Two interfaces for CDC-ACM. - One interface for vendor.
`USBD_CFG_MAX_NBR_IF_ALT`	7	No alternate interface needed, but this value must at least be equal to `USBD_CFG_MAX_NBR_IF`.
`USBD_CFG_MAX_NBR_IF_GRP`	2	CDC-ACM needs to group its communication and data interfaces into a single USB function. Since there are two CDC-ACM class instances, there will be two interface groups.
`USBD_CFG_MAX_NBR_EP_DESC`	9, 10, 11 or 12	One IN and (optional) OUT interrupt endpoint for HID. Three endpoints for first CDC-ACM class instance. Three endpoints for second CDC-ACM class instance. Two bulk plus two optional interrupt endpoints for vendor.
`USBD_CFG_MAX_NBR_EP_OPEN`	8, 9, 10 or 11	In the worst case (host enables second configuration): Two control endpoints for device’s standard requests. One IN and (optional) OUT interrupt endpoint for HID. Three endpoints for second CDC-ACM class instance. Two bulk plus two optional interrupt endpoints for vendor.
`USBD_HID_CFG_MAX_NBR_DEV`	1	Only one instance of HID class is needed. It will be shared between all the configurations.
`USBD_HID_CFG_MAX_NBR_CFG`	4	HID class instance can be used in all of device’s configurations.
`USBD_CDC_CFG_MAX_NBR_DEV`	2	Two CDC base class instances are used.
`USBD_CDC_CFG_MAX_NBR_CFG`	2	Each CDC base class instance can be used in one full-speed and one high-speed configuration.
`USBD_ACM_SERIAL_CFG_MAX_NBR_DEV`	2	Two ACM subclass instances are used.
`USBD_VENDOR_CFG_MAX_NBR_DEV`	1	Only one vendor class instance is used.
`USBD_VENDOR_CFG_MAX_NBR_CFG`	2	The vendor class instance can be used in one full-speed and one high-speed configuration.

Table - Configuration Example of a Complex Composite High-Speed USB Device

Device Driver Guide

There are many USB device controllers available on the market and each requires a driver to work with µC/USB-Device. The amount of code necessary to port a specific device to µC/USB-Device greatly depends on the device's complexity.

If not already available, a driver can be developed, as described in this chapter. However, it is recommended to modify an already existing device driver with the new device's specific code following the Micrium coding convention for consistency. It is also possible to adapt drivers written for other USB device stacks, especially if the driver is short and it is a matter of simply copying data to and from the device.

This section describes the hardware (device) driver architecture for µC/USB-Device, including:

- Device Driver API Definition(s)
- Device Configuration
- Memory Allocation
- CPU and Board Support

Micrium provides sample configuration code free of charge; however, the sample code will likely require modifications depending on the combination of processor, evaluation board, and USB device controller(s).

General Information

Model

No particular memory interface is required by µC/USB-Device's driver model. Therefore, the USB device controller may use the assistance of a Direct Memory Access (DMA) controller to transfer data or handle the data transfers directly.

API

All device drivers must declare an instance of the appropriate device driver API structure as a global variable within the source code. The API structure is an ordered list of function pointers utilized by µC/USB-Device when device hardware services are required.

A sample device driver API structure is shown below.

```
const  USBD_DRV_API  USBD_DrvAPI_<controller> = { USBD_DrvInit,               (1)
                                                  USBD_DrvStart,              (2)
                                                  USBD_DrvStop,               (3)
                                                  USBD_DrvAddrSet,            (4)
                                                  USBD_DrvAddrEn,             (5)
                                                  USBD_DrvCfgSet,             (6)
                                                  USBD_DrvCfgClr,             (7)
                                                  USBD_DrvGetFrameNbr,        (8)
                                                  USBD_DrvEP_Open,            (9)
                                                  USBD_DrvEP_Close,          (10)
                                                  USBD_DrvEP_RxStart,        (11)
                                                  USBD_DrvEP_Rx,             (12)
                                                  USBD_DrvEP_RxZLP,          (13)
                                                  USBD_DrvEP_Tx,             (14)
                                                  USBD_DrvEP_TxStart,        (15)
                                                  USBD_DrvEP_TxZLP,          (16)
                                                  USBD_DrvEP_Abort,          (17)
                                                  USBD_DrvEP_Stall,          (18)
                                                  USBD_DrvISR_Handler        (19)
};
```

Listing - Device Driver Interface API

(1) Device initialization/add

(2) Device start

(3) Device stop

(4) Assign device address

(5) Enable device address

(6) Set device configuration

(7) Clear device configuration

(8) Retrieve frame number

(9) Open device endpoint

(10) Close device endpoint

(11) Configure device endpoint to receive data

(12) Receive from device endpoint

(13) Receive zero-length packet from device endpoint

(14) Configure device endpoint to transmit data

(15) Transmit to device endpoint

(16) Transmit zero-length packet to device endpoint

(17) Abort device endpoint transfer

(18) Stall device endpoint

(19) Device interrupt service routine (ISR) handler

Some non-essential functions can also be declared as null pointers. The functions that can be declared as null pointers are: `AddrSet()`, `AddrEn()`, `CfgSet()`, `CfgClr()` and `FrameNbrGet()`. Please note that while these functions are not essential for the core to work properly, the USB device driver used may require some or all of them to work correctly.

The Listing - Device Driver Interface API with Null Pointers in the *General Information* page shows a sample API structure with only the mandatory functions declared.

```
const  USBD_DRV_API  USBD_DrvAPI_<controller> = { USBD_DrvInit,
                                                  USBD_DrvStart,
                                                  USBD_DrvStop,
                                                  DEF_NULL,
                                                  DEF_NULL,
                                                  DEF_NULL,
                                                  DEF_NULL,
                                                  DEF_NULL,
                                                  USBD_DrvEP_Open,
                                                  USBD_DrvEP_Close,
                                                  USBD_DrvEP_RxStart,
                                                  USBD_DrvEP_Rx,
                                                  USBD_DrvEP_RxZLP,
                                                  USBD_DrvEP_Tx,
                                                  USBD_DrvEP_TxStart,
                                                  USBD_DrvEP_TxZLP,
                                                  USBD_DrvEP_Abort,
                                                  USBD_DrvEP_Stall,
                                                  USBD_DrvISR_Handler
};
```

Listing - Device Driver Interface API with Null Pointers

The details of each device driver API function are described in the Device Controller Driver API Reference.

It is the device driver developers' responsibility to ensure that the required functions listed within the API are properly implemented and that the order of the functions within the API structure is correct.

µC/USB-Device device driver API function names may not be unique. Name clashes between device drivers are avoided by never globally prototyping device driver functions and ensuring that all references to functions within the driver are obtained by pointers within the API structure. The developer may arbitrarily name the functions within the source file so long as the API structure is properly declared. The user application should never need to call API functions. Unless special care is taken, calling device driver functions may lead to unpredictable results due to reentrancy.

When writing your own device driver, you can assume that each driver API function accepts a pointer to a structure of the type `USBD_DRV` as one of its parameters. Through this structure, you will be able to access the following fields:

```
typedef  struct  usbd_drv  USBD_DRV;

typedef  usb_drv {
    CPU_INT08U         DevNbr;                                           (1)
    USBD_DRV_API      *API_Ptr;                                          (2)
    USBD_DRV_CFG      *CfgPtr;                                           (3)
    void              *DataPtr;                                          (4)
    USBD_DRV_BSP_API  *BSP_API_Ptr;                                      (5)
};
```

Listing - USB Device Driver Data Type

(1) Unique index to identify device.

(2) Pointer to USB device controller driver API.

(3) Pointer to USB device controller driver configuration.

(4) Pointer to USB device controller driver specific data.

(5) Pointer to USB device controller BSP.

Memory Allocation

Memory allocation in the driver can be simplified by the use of memory allocation functions available from Micrium’s µC/LIB module. µC/LIB’s memory allocation functions provide allocation of memory from dedicated memory space (e.g., USB RAM) or general purpose heap. The driver may use the pool functionality offered by µC/LIB. Memory pools use fixed-sized blocks that can be dynamically allocated and freed during application execution. Memory pools may be convenient to manage objects needed by the driver. The objects could be for instance data structures mandatory for DMA operations. For more information on using µC/LIB memory allocation functions, consult the µC/LIB documentation.

CPU and Board Support

In order for device drivers to be platform-independent, it is necessary to provide a layer of code that abstracts details such as clocks, interrupt controllers, input/output (I/O) pins, and other hardware modules configuration. With this board support package (BSP) code layer, it is possible for the majority of the USB device stack to be independent of any specific hardware, and for device drivers to be reused on different architectures and bus configurations without the need to modify stack or driver source code. These procedures are also referred as the USB BSP for a particular development board.

A sample device BSP interface API structure is shown below.

```
const  USBD_DRV_BSP_API  USBD_DrvBSP_<controller> = { USBD_BSP_Init,          (1)
                                                       USBD_BSP_Conn,          (2)
                                                       USBD_BSP_Disconn        (3)
};
```

Listing - Device BSP Interface API

(1) Device BSP initialization function pointer

(2) Device BSP connect function pointer

(3) Device BSP disconnect function pointer

The details of each device BSP API function are described in the Device Driver BSP Functions Reference.

Interrupt Handling

Interrupt handling is accomplished using the following multi-level scheme.

- Processor level kernel-aware interrupt handler
- Device driver interrupt handler

During initialization, the device driver registers all necessary interrupt sources with the BSP interrupt management code. You can also accomplish this by plugging an interrupt vector table during compile time. Once the global interrupt vector sources are configured and an interrupt occurs, the system will call the first-level interrupt handler. The first-level interrupt handler is responsible for performing all kernel required steps prior to calling the USB device driver interrupt handler: `USBD_DrvISR_Handler()`. Depending on the platform architecture (that is the way the kernel handles interrupts) and the USB device controller interrupt vectors, the device driver interrupt handler implementation may follow the models below.

Single USB ISR Vector with ISR Handler Argument

If the platform architecture allows parameters to be passed to ISR handlers and the USB device controller has a single interrupt vector for the USB device, the first-level interrupt handler may be defined as:

Prototype

```
void  USBD_BSP_<controller>_IntHandler (void  *p_arg);
```

Arguments

`p_arg`

Pointer to USB device driver structure that must be typecast to a pointer to `USBD_DRV`.

Notes / Warnings

None.

Single USB ISR Vector

If the platform architecture does not allow parameters to be passed to ISR handlers and the USB device controller has a single interrupt vector for the USB device, the first-level interrupt handler may be defined as:

Prototype

```
void  USBD_BSP_<controller>_IntHandler (void);
```

Arguments

None.

Notes / Warnings

In this configuration, the pointer to the USB device driver structure must be stored globally in the driver. Since the pointer to the USB device structure is never modified, the BSP initialization function, `USBD_BSP_Init()`, can save its address for later use.

Multiple USB ISR Vectors with ISR Handler Arguments

If the platform architecture allows parameters to be passed to ISR handlers and the USB device controller has multiple interrupt vectors for the USB device (e.g., USB events, DMA transfers), the first-level interrupt handler may need to be split into multiple sub-handlers. Each sub-handler would be responsible for managing the status reported to the different vectors. For example, the first-level interrupt handlers for a USB device controller that redirects USB events to one interrupt vector and the status of DMA transfers to a second interrupt vector may be defined as:

Prototype

```
void  USBD_BSP_<controller>_EventIntHandler (void  *p_arg);
void  USBD_BSP_<controller>_DMA_IntHandler  (void  *p_arg);
```

Arguments

`p_arg`

Pointer to USB device driver structure that must be typecast to a pointer to `USBD_DRV`.

Notes / Warnings

None.

Multiple USB ISR Vectors

If the platform architecture does not allow parameters to be passed to ISR handlers and the USB device controller has multiple interrupt vectors for the USB device (e.g., USB events, DMA transfers), the first-level interrupt handler may need to be split into multiple sub-handlers. Each sub-handler would be responsible for managing the status reported to the different vectors. For example, the first-level interrupt handlers for a USB device controller that redirects USB events to one interrupt vector and the status of DMA transfers to a second interrupt vector may be defined as:

Prototype

```
void  USBD_BSP_<controller>_EventIntHandler (void);
void  USBD_BSP_<controller>_DMA_IntHandler  (void);
```

Arguments

None.

Notes / Warnings

In this configuration, the pointer to the USB device driver structure must be stored globally in the driver. Since the pointer to the USB device structure is never modified, the BSP initialization function, `USBD_BSP_Init()`, can save its address for later use.

Using USBD_DrvISR_Handler()

The device driver interrupt handler must notify the USB device stack of various status changes. The Table - Status Notification API in the *Interrupt Handling* page shows each type of status change and the corresponding notification function.

USB Event	Function associated
Connect Event	`USBD_EventConn()`
Disconnect Event	`USBD_EventDisconn()`
Reset Event	`USBD_EventReset()`
Suspend Event	`USBD_EventSuspend()`
Resume Event	`USBD_EventResume()`
High-Speed Handshake Event	`USBD_EventHS()`
Setup Packet	`USBD_EventSetup()`
Receive Packet Completed	`USBD_EP_RxCmpl()`
Transmit Packet Completed	`USBD_EP_TxCmpl()`

Table - Status Notification API

Each status notification API queues the event type to be processed by the USB stack's event processing task. Upon reception of a USB event, the interrupt service routine may perform some operations associated to the event before notifying the stack. For example, the USB device controller driver must perform the proper actions for the bus reset when an interrupt request for that event is triggered. Additionally, it must also notify the USB device stack about the bus reset event by invoking the proper status notification API. In general, the device driver interrupt handler must perform the following functions:

1. Determine which type of interrupt event occurred by reading an interrupt status register.

2. If a receive event has occurred, the driver must post the successful completion or the error status to the USB device stack by calling `USBD_EP_RxCmpl()` for each transfer received.

3. If a transmit complete event has occurred, the driver must post the successful completion or the error status to the USB device stack by calling `USBD_EP_TxCmpl()` for each transfer transmitted.

4. If a setup packet event has occurred, the driver must post the setup packet data in little-endian format to the USB device stack by calling `USBD_EventSetup()`.

5. All other events must be posted to the USB device stack by a call to their corresponding status notification API from Table - Status Notification API in the *Interrupt Handling* page. This allows the USB device stack to broadcast these event notifications to the classes.

6. Clear local interrupt flags.

Device Configuration

The USB device characteristics must be shared with the USB device stack through configuration parameters. All of these parameters are provided through two global structures of type `USBD_DRV_CFG` and `USBD_DEV_CFG`. These structures are declared in the file `usbd_dev_cfg.h`, and defined in the file `usbd_dev_cfg.c` (refer to the Copying and Modifying Template Files section for an example of initializing these structures). These files are distributed as templates, and you should modify them to have the proper configuration for your USB device controller.

Driver Configuration

The fields of the following structure are the parameters needed to configure the USB device controller driver:

```
typedef  const  struct  usb_drv_cfg {
    CPU_ADDR           BaseAddr;                                              (1)
    CPU_ADDR           MemAddr;                                               (2)
    CPU_ADDR           MemSize;                                               (3)
    USBD_DEV_SPD       Spd;                                                   (4)
    USBD_DRV_EP_INFO  *EP_InfoTbl;                                            (5)
} USBD_DRV_CFG;
```

Listing - USB Device Controller Driver Configuration Structure

(1) Base address of the USB device controller hardware registers.

(2) Base address of the USB device controller dedicated memory.

(3) Size of the USB device controller dedicated memory.

(4) Speed of the USB device controller. Can be set to either `USBD_DEV_SPD_LOW`, `USBD_DEV_SPD_FULL` or `USBD_DEV_SPD_HIGH`.

(5) USB device controller endpoint information table.

Device Configuration

The fields of the following structure are the parameters needed to configure the USB device:

```
typedef  const  struct  usb_dev_cfg {
           CPU_INT16U   VendorID;                                            (1)
           CPU_INT16U   ProductID;                                           (2)
           CPU_INT16U   DeviceBCD;                                           (3)
    const  CPU_CHAR    *ManufacturerStrPtr;                                  (4)
    const  CPU_CHAR    *ProductStrPtr;                                       (5)
    const  CPU_CHAR    *SerialNbrStrPtr;                                     (6)
           CPU_INT16U   LangID;                                              (7)
} USBD_DEV_CFG;
```

Listing - USB Device Configuration Structure

(1) Vendor ID.

(2) Product ID.

(3) Device release number.

(4) Pointer to manufacturer string.

(5) Pointer to product string.

(6) Pointer to serial number ID.

(7) Language ID.

Driver Endpoint Information Table

The endpoint information table provides the hardware endpoint characteristics to the USB device stack. When an endpoint is opened, the USB device stack's core iterates through the endpoint information table entries until the endpoint type and direction match the requested endpoint characteristics. The matching entry provides the physical endpoint number and maximum packet size information to the USB device stack. The entries on the endpoint information table are organized as follows:

```
typedef  const  struct  usbd_drv_ep_info {
    CPU_INT08U  Attrib;                                                     (1)
    CPU_INT08U  Nbr;                                                        (2)
    CPU_INT16U  MaxPktSize;                                                 (3)
} USBD_DRV_EP_INFO;
```

Listing - Endpoint Information Table Entry

(1) The endpoint Attrib is a combination of the endpoint type `USBD_EP_INFO_TYPE` and endpoint direction `USBD_EP_INFO_DIR` attributes. The endpoint type can be defined as: `USBD_EP_INFO_TYPE_CTRL`, `USBD_EP_INFO_TYPE_INTR`, `USBD_EP_INFO_TYPE_BULK`, or `USBD_EP_INFO_TYPE_ISOC`. The endpoint direction can be defined as either `USBD_EP_INFO_DIR_IN` or `USBD_EP_INFO_DIR_OUT`.

(2) The endpoint `Nbr` is the logical endpoint number used by the USB device controller.

(3) The endpoint `MaxPktSize` defines the maximum packet size supported by the hardware. The maximum packet size used by the USB device stack is validated to comply with the USB standard guidelines.

An example of an endpoint information table for a high-speed capable device is provided below.

```
const  USBD_DRV_EP_INFO  USBD_DrvEP_InfoTbl_<controller>[] = {
                                                                            (1)
    {USBD_EP_INFO_TYPE_CTRL                       |USBD_EP_INFO_DIR_OUT, 0u,   64u},
    {USBD_EP_INFO_TYPE_CTRL                       |USBD_EP_INFO_DIR_IN,  0u,   64u},
                                                                            (2)
    {USBD_EP_INFO_TYPE_BULK|USBD_EP_INFO_TYPE_INTR|USBD_EP_INFO_DIR_OUT, 1u, 1024u},
    {USBD_EP_INFO_TYPE_BULK|USBD_EP_INFO_TYPE_INTR|USBD_EP_INFO_DIR_IN,  1u, 1024u},
                                                                            (3)
    {DEF_BIT_NONE                                                   ,  0u,    0u}
};
```

Listing - Example of Endpoint Information Table Configuration

(1) An endpoint described only by one type and one direction is a dedicated endpoint. Most of the device controllers will have a dedicated endpoint for control OUT and IN endpoints. That’s why the table `USBD_DrvEP_InfoTbl_<controller>` is first initialized

with two dedicated control endpoints.

(2) An endpoint indicating several types and two possible directions is a configurable endpoint. In this example, the endpoint can be configured as a bulk or interrupt OUT endpoint. An endpoint fully configurable in terms of type and direction would be OR'ed with this format:
`USBD_EP_INFO_TYPE_CTRL | USBD_EP_INFO_TYPE_INTR | USBD_EP_INFO_TYPE_BULK | USBD_EP_INFO_TYPE_ISOC | USBD_EP_INFO_DIR_IN | USBD_EP_INFO_DIR_OUT`.

(3) The last entry on the endpoint information table must be an empty entry to allow the USB device stack to determine the end of the table.

USB Device Driver Functional Model

The USB device controller can operate in distinct modes while transferring data. This section describes the common sequence of operations for the receive and transmit API functions in the device driver, highlighting potential differences when the controller is operating on FIFO or DMA mode. While there are some controllers that are strictly FIFO-based or DMA-based, there are controllers that can operate in both modes depending on hardware characteristics. For this type of controller, the device driver will employ the appropriate sequence of operations depending, for example, on the endpoint type.

Device Synchronous Receive

The device synchronous receive operation is initiated by the calls: `USBD_BulkRx()`, `USBD_CtrlRx()`, and `USBD_IntrRx()`. The Figure - Device Synchronous Receive Diagram in the *USB Device Driver Functional Model* page shows an overview of the device synchronous receive operation.

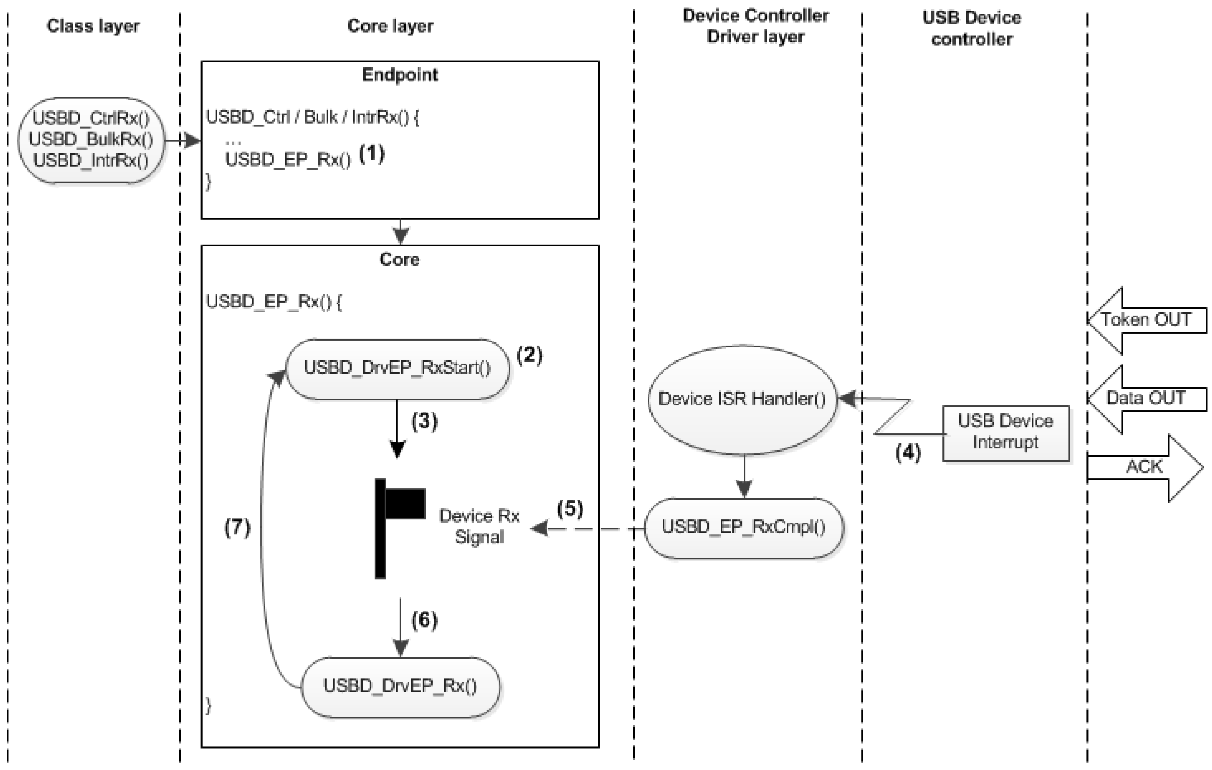


Figure - Device Synchronous Receive Diagram

(1) The upper layer functions (`USBD_BulkRx()`, `USBD_CtrlRx()`, and `USBD_IntrRx()`) lock the endpoint and call `USBD_EP_Rx()`.

(2) In `USBD_EP_RX()`, `USBD_DrvEP_RxStart()` is invoked.

On DMA-based controllers, this device driver API is responsible for queuing a receive transfer. The queued receive transfer does not need to satisfy the whole requested transfer length in one single transaction. If multiple transfers are queued only the last queued transfer must be signaled to the USB device stack. This is required since the USB device stack iterates through the receive process until all requested data or a short packet has been received. This function must also return the maximum amount of bytes that will be received. Typically this value will be the lowest value between the maximum transfer size and the amount of bytes requested by the core.

On FIFO-based controllers, this device driver API is responsible for enabling data to be received into the endpoint FIFO, including any related ISR's. The function must return the maximum amount of bytes that will be received. Typically this value will be the lowest value between the FIFO size and the amount of bytes requested by the core.

(3) While data is being received, the device synchronous receive operation waits on the device receive signal, during which the endpoint is unlocked.

(4) The USB device controller triggers an interrupt request when it is finished receiving the data. This invokes the USB device driver interrupt service routine (ISR) handler, directly or indirectly, depending on the architecture.

(5) Inside the USB device driver ISR handler, the type of interrupt request is determined to be a receive interrupt. `USBD_EP_RxCmpl()` is called to unblock the device receive signal. The endpoint is re-locked.

(6) The device receive operation reaches the `USBD_EP_Rx()`, which internally calls `USBD_DrvEP_Rx()`.

On DMA-based controllers, this device driver API is responsible for de-queuing the completed receive transfer and returning the amount of data received. In case the DMA-based controller requires the buffered data to be placed in a dedicated USB memory region, the buffered data must be transferred into the application buffer area.

On FIFO-based controllers, this device driver API is responsible for reading the amount of data received by copying it into the application buffer area and returning the data back to its caller.

(7) The device receive operation iterates through the process until the amount of data received matches the amount requested, or a short packet is received. The endpoint is unlocked.

Device Asynchronous Receive

The device asynchronous receive operation is initiated by the calls: `USBD_BulkRxAsync()`, `USBD_IntrRxAsync()` and `USBD_IsocRxAsync()`. Figure - Device Asynchronous Receive Diagram in the *USB Device Driver Functional Model* page shows an overview of the device asynchronous receive operation.

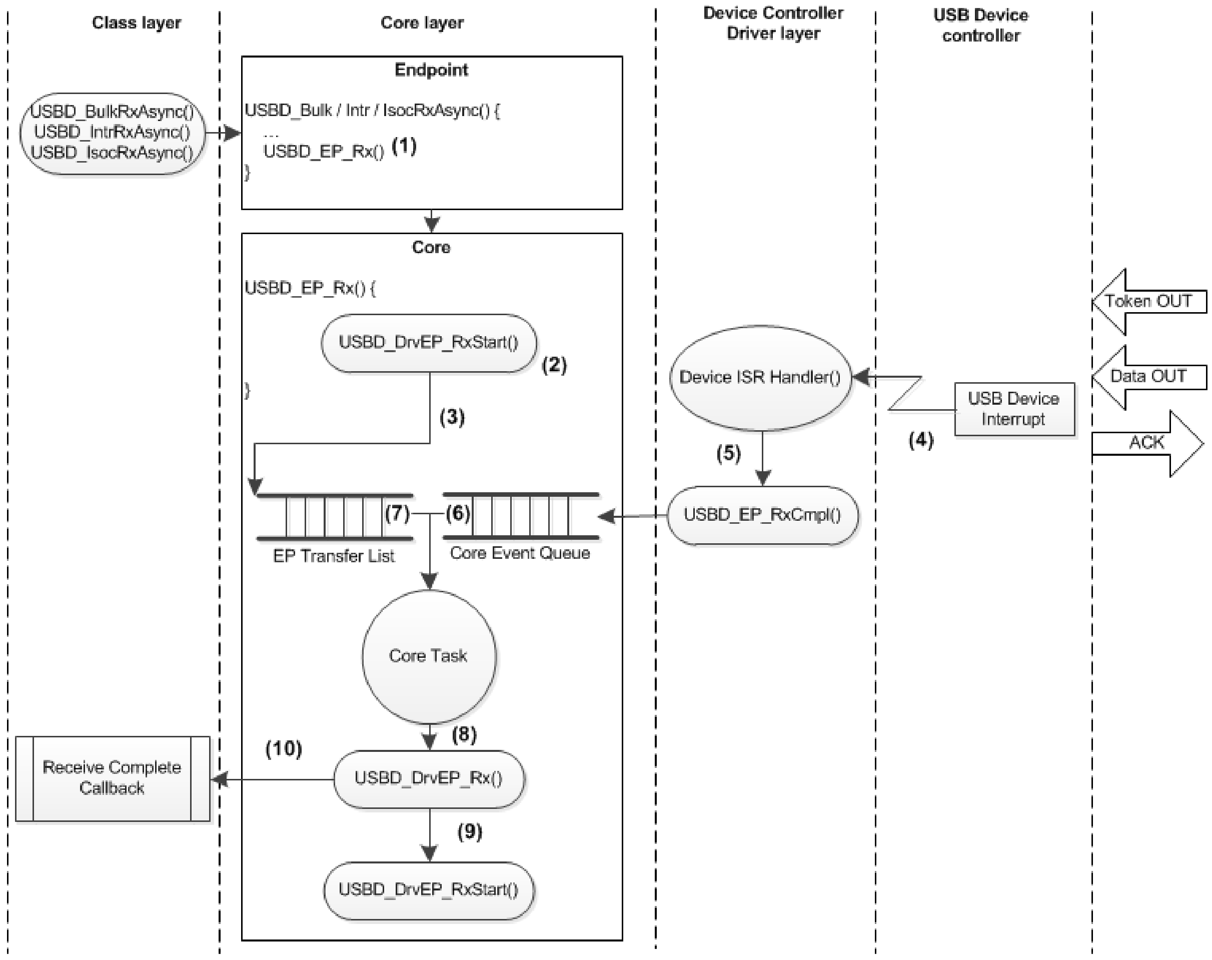


Figure - Device Asynchronous Receive Diagram

(1) The upper layer functions (`USBD_BulkRxAsync()`, `USBD_IntrRxAsync()` and `USBD_IsocRxAsync()`) lock the endpoint and call `USBD_EP_Rx()`, passing a receive complete callback function as an argument.

(2) In `USBD_EP_Rx()`, the `USBD_DrvEP_RxStart()` function is invoked in the same way as for the synchronous operation.

On DMA-based controllers, this device driver API is responsible for queuing a receive transfer. The queued receive transfer does not need to satisfy the whole requested transfer length in one single transaction. If multiple transfers are queued only the last queued transfer must be signaled to the USB device stack. This is required since the USB device stack iterates through the receive process until all requested data or a short packet has been received. This function must also return the maximum amount of bytes that will be received. Typically this value will be the lowest value between the maximum transfer size and the amount of bytes requested by the core.

On FIFO-based controllers, this device driver API is responsible for enabling data to be received into the endpoint FIFO, including any related ISR's. The function must return the maximum amount of bytes that will be received. Typically this value will be the lowest value between the FIFO size and the amount of bytes requested by the core.

In both cases, no more transfers can be queued on that endpoint if the maximum amount of bytes that can be received is lower than the amount requested by the application. For example, if the application wishes to receive 1000 bytes but that the driver can only receive up to 512 bytes per transfer, `USBD_DrvEP_RxStart()` will return 512 as the maximum number of bytes that could be received. In this case, no other transfer can be queued on that endpoint at this moment. When this first transfer completes, another transfer of 488 (1000 - 512) bytes will be queued. Since the driver will return 488 as the maximum byte it can receive (the amount requested), it would be possible to queue another transfer at that moment.

(3) The transfer is added to the endpoint transfer list, if possible. That is, the driver must be able to queue the transfer too, there must not be a synchronous transfer currently in progress on that same endpoint and there must not be a partial asynchronous transfer queued on that endpoint (see note #2). The call to `USBD_EP_Rx()` immediately returns (with the appropriate error value, if any) to the application (without blocking) and the endpoint is unlocked while data is being received.

(4) The USB device controller triggers an interrupt request when it is finished receiving the data. This invokes the USB device driver interrupt service routine (ISR) handler, directly or indirectly, depending on the architecture.

(5) Inside the USB device driver ISR handler, the type of interrupt request is determined to be a receive interrupt. `USBD_EP_RxCmpl()` is called to queue the core event for the endpoint that had its transfer completed.

(6) The core task de-queues the core event indicating a completed transfer.

(7) The core task invokes `USBD_EP_XferAsyncProcess()`, which locks the endpoint and gets the first completed transfer in the endpoint transfer list.

(8) The core task internally calls `USBD_DrvEP_Rx()` for the completed transfer.

On DMA-based controllers, this device driver API is responsible for de-queuing the completed receive transfer and returning the amount of data received. In case the DMA-based controller requires the buffered data to be placed in a dedicated USB memory region, the buffered data must be transferred into the application buffer area.

On FIFO-based controllers, this device driver API is responsible for reading the amount of data received by copying it into the application buffer area and returning the data back to its caller.

(9) If the overall amount of data received is less than the amount requested and the current transfer is not a short packet, `USBD_DrvEP_RxStart()` is called (see note #2) to request the remaining data. Endpoint is unlocked afterwards.

(10) The receive operation finishes when the amount of data received matches the amount requested, or a short packet is received. The endpoint is unlocked and the receive complete callback is invoked to notify the application about the completion of the process.

Device Synchronous Transmit

The device synchronous transmit operation is initiated by the calls: `USBD_BulkTx()`, `USBD_CtrlTx()`, and `USBD_IntrTx()`. Figure - Device Synchronous Transmit Diagram in the *USB Device Driver Functional Model* page shows an overview of the device synchronous transmit operation.

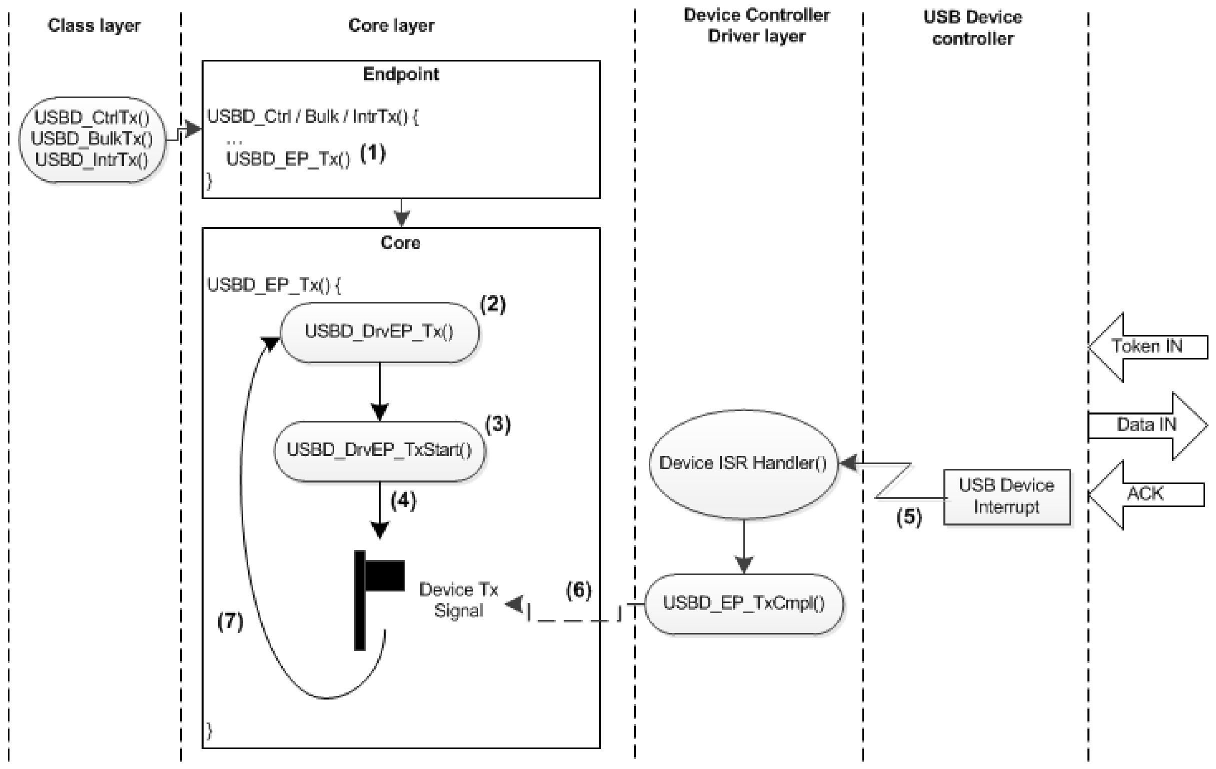


Figure - Device Synchronous Transmit Diagram

(1) The upper layer functions (`USBD_BulkTx()`, `USBD_CtrlTx()`, and `USBD_IntrTx()`) lock the endpoint and call `USBD_EP_Tx()`.

(2) In `USBD_EP_Tx()`, `USBD_DrvEP_Tx()` is invoked.

On DMA-based controllers, this device driver API is responsible for preparing the transmit transfer/descriptor and returning the amount of data to transmit. In case the DMA-based controller requires the buffered data to be placed in a dedicated USB memory region, the contents of the application buffer area must be transferred into the dedicated memory region.

On FIFO-based controllers, this device driver API is responsible for writing the amount of data to transfer into the FIFO and returning the amount of data to transmit.

(3) The `USBD_DrvEP_TxStart()` API starts the transmit process.

On DMA-based controllers, this device driver API is responsible for queuing the DMA transmit descriptor and enabling DMA transmit complete ISR's.

On FIFO-based controllers, this device driver API is responsible for enabling transmit complete ISR's.

(4) While data is being transmitted, the device synchronous transmit operation waits on the device transmit signal, during which the endpoint is unlocked.

(5) The USB device controller triggers an interrupt request when it is finished transmitting the data. This invokes the USB device driver interrupt service routine (ISR) handler, directly or indirectly, depending on the architecture.

(6) Inside the USB device driver ISR handler, the type of interrupt request is determined as a transmit interrupt. `USBD_EP_TxCmpl()` is called to unblock the device transmit signal. The endpoint is re-locked.

On DMA-based controllers, the transmit transfer is de-queued from a list of completed transfers.

(7) The device transmit operation iterates through the process until the amount of data transmitted matches the requested amount. The endpoint is unlocked.

Device Asynchronous Transmit

The device asynchronous transmit operation is initiated by the calls: `USBD_BulkTxAsync()`, `USBD_IntrTxAsync()` and `USBD_IsocTxAsync()`. Figure - Device Asynchronous Transmit Diagram in the *USB Device Driver Functional Model* page shows an overview of the device asynchronous transmit operation.

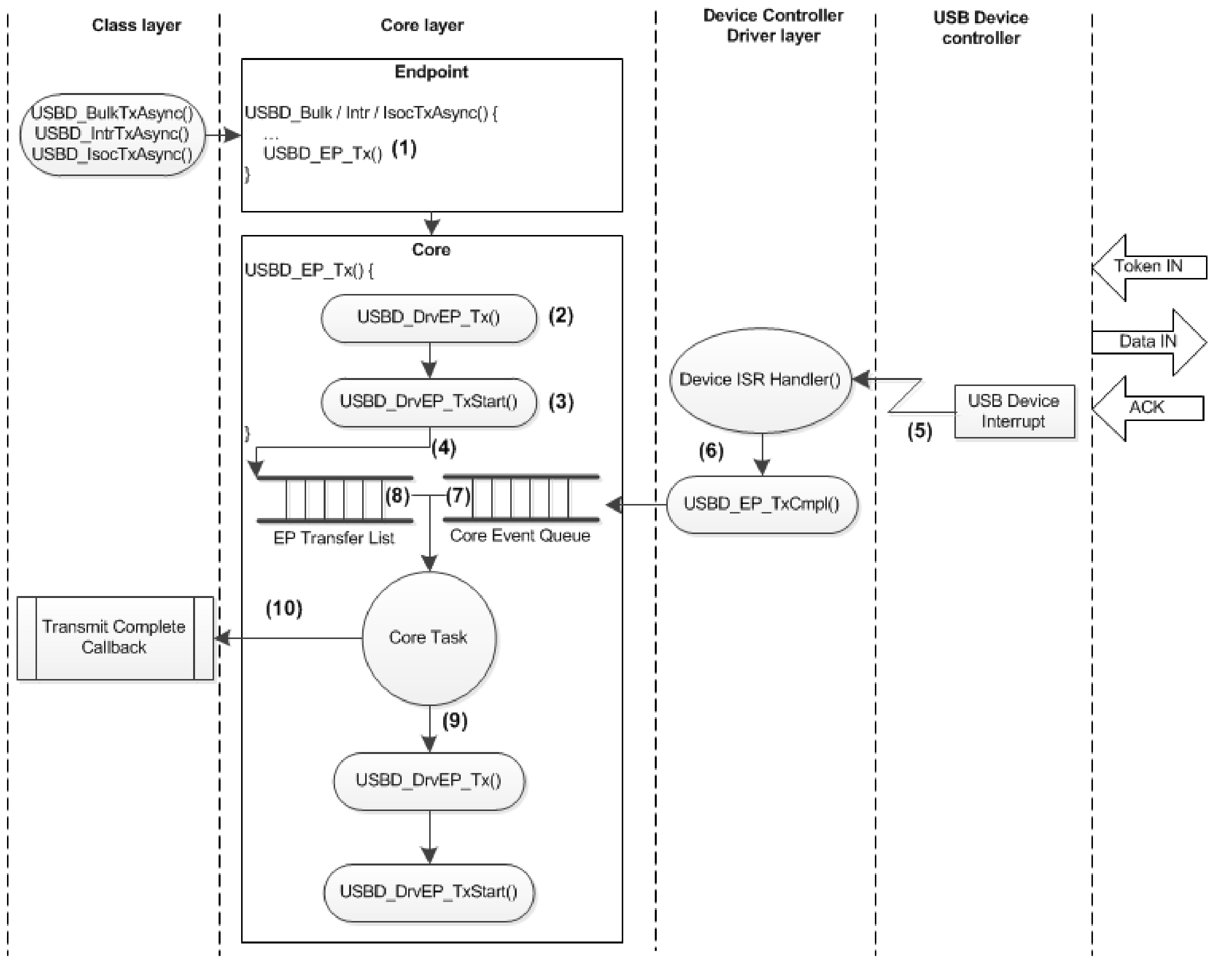


Figure - Device Asynchronous Transmit Diagram

(1) The upper layer functions (`USBD_BulkTxAsync()`, `USBD_IntrTxAsync()` and `USBD_IsocTxAsync()`) lock the endpoint call `USBD_EP_Tx()` passing a transmit complete callback function as an argument.

(2) In `USBD_EP_Tx()`, the `USBD_DrvEP_Tx()` function is invoked in the same way as for the synchronous operation.

On DMA-based controllers, this device driver API is responsible for preparing the transmit transfer/descriptor and returning the amount of data to transmit. In case the DMA-based controller requires the buffered data to be placed in a dedicated USB memory region, the contents of the application buffer area must be transferred into the dedicated memory region.

On FIFO-based controllers, this device driver API is responsible for writing the amount of data to transfer into the FIFO and returning the amount of data to transmit.

In both cases, no more transfers can be queued on that endpoint if the maximum amount of bytes that can be transmitted is lower than the amount requested by the application. For example, if the application wishes to transmit 1000 bytes but that the driver can only transmit up to 512 bytes per transfer, `USBD_DrvEP_Tx()` will return 512 as the maximum number of bytes that could be transmitted. In this case, no other transfer can be queued on that endpoint at this moment. When this first transfer completes, another transfer of 488 (1000 - 512) bytes will be queued. Since the driver will return 488 as the maximum byte it can transmit (the amount requested), it would be possible to queue another transfer at that moment.

(3) The `USBD_DrvEP_TxStart()` API starts the transmit process.

On DMA-based controllers, this device driver API is responsible for queuing the DMA transmit descriptor and enabling DMA transmit complete ISR's.

On FIFO-based controllers, this device driver API is responsible for enabling transmit complete ISR's.

(4) The transfer is added to the endpoint transfer list, if possible. That is, the driver must be able to queue the transfer too, there must not be a synchronous transfer currently in progress on that same endpoint and there must not be a partial asynchronous transfer queued on that endpoint (see note #2). The call to `USBD_EP_Tx()` returns immediately to the application (without blocking) and the endpoint is unlocked while data is being transmitted.

(5) The USB device controller triggers an interrupt request when it is finished transmitting the data. This invokes the USB device driver interrupt service routine (ISR) handler, directly or indirectly, depending on the architecture.

(6) Inside the USB device driver ISR handler, the type of interrupt request is determined as a transmit interrupt. `USBD_EP_TxCmpl()` is called to queue the endpoint that had its transfer completed.

On DMA-based controllers, the transmit transfer is de-queued from the list of completed transfers.

(7) The core task de-queues the core event indicating a completed transfer.

(8) The core task invokes `USBD_EP_XferAsyncProcess()`, which locks the endpoint and gets the first completed transfer in the endpoint transfer list.

(9) If the overall amount of data transmitted is less than the amount requested, `USBD_DrvEP_Tx()` and `USBD_DrvEP_TxStart()` are called to transmit the remaining amount of data. Endpoint is then unlocked.

(10) The device transmit operation finishes when the amount of data transmitted matches the amount requested. The endpoints is unlocked and the transmit complete callback is invoked to notify the application about the completion of the process.

Device Set Address

The device set address operation is performed by the setup transfer handler when a `SET_ADDRESS` request is received. Figure - Device Set Address Diagram in the *USB Device Driver Functional Model* page shows an overview of the device set address operation.

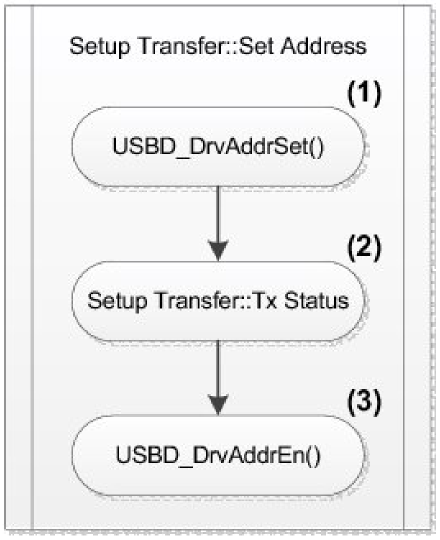


Figure - Device Set Address Diagram

(1) Once the arguments of the setup request are validated, `USBD_DrvAddrSet()` is called to inform the device driver layer of the new address. For controllers that have hardware assistance in setting the device address after the status stage, this device driver API is used to configure the device address and enable the transition after the status stage. For controllers that activate the device address as soon as configured, this device driver API should not perform any action.

(2) The setup request status stage is transmitted to acknowledge the address change.

(3) After the status stage, the `USBD_DrvAddrEn()` is called to inform the device driver layer to enable the new device address. For controllers that activate the device address as soon as configured, this device driver API is responsible for setting and enabling the new device address. For controllers that have hardware assistance in setting the device address after the status stage, this device driver API should not perform any action, since `USBD_DrvAddrSet()` has already taken care of setting the new device.

USB Classes

The USB classes available for the µC/USB-Device stack have some common characteristics. This chapter explains these characteristics and the interactions with the core layer allowing you to better understand the operation of classes.

Class Instance Concept

The USB classes available with the µC/USB-Device stack implement the concept of class instances. A class instance represents one function within a device. The function can be described by one interface or by a group of interfaces and belongs to a certain class.

Each USB class implementation has some configuration and functions in common based on the concept of class instance. The common configuration and functions are presented in Table - Constants and Functions Related to the Concept of Multiple Class Instances in the *Class Instance Concept* page. In the column title 'Constants or Function', the placeholder `XXXX` can be replaced by the name of the class: AUDIO (Audio for function names), CDC, HID, MSC, PHDC or VENDOR (Vendor for function names).

Constant or function	Description
`USBD_XXXX_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances.
`USBD_XXXX_CFG_MAX_NBR_CFG`	Configures the maximum number of configurations per device. During the class initialization, a created class instance will be added to one or more configurations.
`USBD_XXXX_Add()`	Creates a new class instance.
`USBD_XXXX_CfgAdd()`	Adds an existing class instance to the specified device configuration.

Table - Constants and Functions Related to the Concept of Multiple Class Instances

In terms of code implementation, the class will declare a local global table that contains a class control structure. The size of the table is determined by the constant `USBD_XXXX_CFG_MAX_NBR_DEV`. This class control structure is associated with one class instance and will contain certain information to manage the class instance. See the Class Instance Structures page for more details about this class control structure.

The following illustrations present several case scenarios. Each illustration is followed by a code listing showing the code corresponding to the case scenario. Figure - Multiple Class Instances - FS Device (1 Configuration with 1 Interface) in the *Class Instance Concept* page represents a typical USB device. The device is Full-Speed (FS) and contains one single configuration. The function of the device is described by one interface composed of a pair of endpoints for the data communication. One class instance is created and it will allow you to manage the entire interface with its associated endpoint.

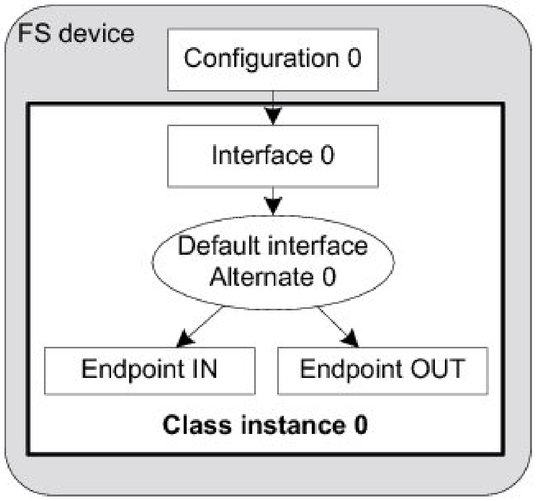


Figure - Multiple Class Instances - FS Device (1 Configuration with 1 Interface)

The code corresponding to Figure - Multiple Class Instances - FS Device (1 Configuration with 1 Interface) in the *Class Instance Concept* page is shown in Listing - Multiple Class Instances - FS Device (1 Configuration with 1 Interface) in the *Class Instance Concept* page.

```
USBD_ERR    err;
CPU_INT08U  class_0;


USBD_XXXX_Init(&err);                                                      (1)
if (err != USBD_ERR_NONE) {
    /* $$$$ Handle the error. */
}

class_0 = USBD_XXXX_Add(&err);                                             (2)
if (err != USBD_ERR_NONE) {
    /* $$$$ Handle the error. */
}

USBD_XXXX_CfgAdd(class_0, dev_nbr, cfg_0, &err);                          (3)
if (err != USBD_ERR_NONE) {
    /* $$$$ Handle the error. */
}
```

Listing - Multiple Class Instances - FS Device (1 Configuration with 1 Interface)

(1) Initialize the class. Any internal variables, structures, and class Real-Time Operating System (RTOS) port will be initialized.

(2) Create the class instance, `class_0`. The function `USBD_XXXX_Add()` allocates a class control structure associated to `class_0`. Depending on the class, besides the parameter

for an error code, `USBD_XXXX_Add()` may have additional parameters representing class-specific information stored in the class control structure.

(3) Add the class instance, `class_0`, to the specified configuration number, `cfg_0`. `USBD_XXXX_CfgAdd()` will create the interface 0 and its associated endpoints IN and OUT. As a result, the class instance encompasses the interface 0 and its endpoints. Any communication done on the interface 0 will use the class instance number, `class_0`.

Figure - Multiple Class Instances - HS/FS Device (2 Configurations and 1 Single Interface) in the *Class Instance Concept* page represents an example of a high-speed capable device. The device can support High-Speed (HS) and Full-Speed (FS). The device will contain two configurations: one valid if the device operates at full-speed and another if it operates at high-speed. In each configuration, interface 0 is the same but its associated endpoints are different. The difference will be the endpoint maximum packet size which varies according to the speed. If a high-speed host enumerates this device, by default, the device will work in high-speed mode and thus the high-speed configuration will be active. The host can learn about the full-speed capabilities by getting a *Device_Qualifier* descriptor followed by an *Other_Speed_Configuration* descriptor. These two descriptors describe a configuration of a high-speed capable device if it were operating at its other possible speed (refer to Universal Serial Bus 2.0 Specification revision 2.0, section 9.6, for more details about these descriptors). In our example, the host may want to reset and enumerate the device again in full-speed mode. In this case, the full-speed configuration is active. Whatever the active configuration, the same class instance is used. Indeed, the same class instance can be added to different configurations. A class instance cannot be added several times to the same configuration.

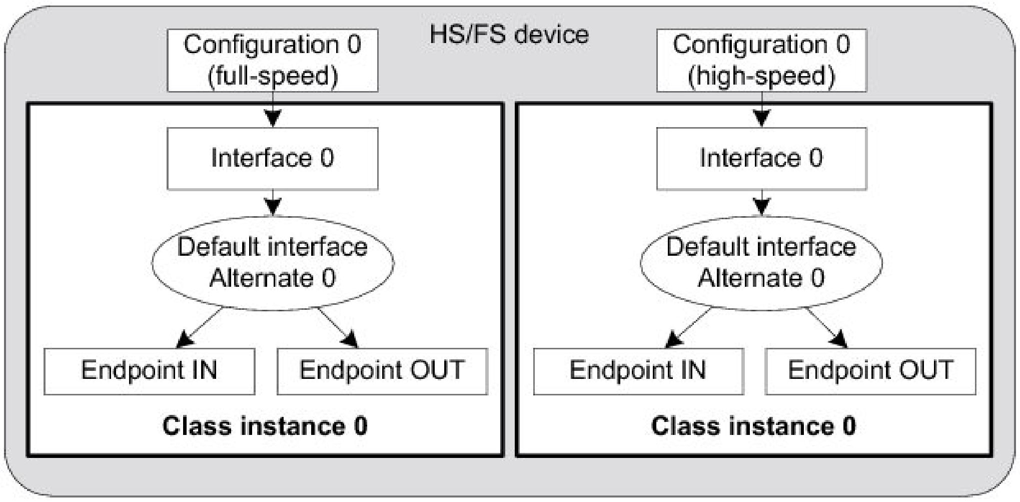

HS/FS device
Configuration 0 (full-speed)
Configuration 0 (high-speed)
Interface 0
Interface 0
Default interface Alternate 0
Default interface Alternate 0
Endpoint IN
Endpoint OUT
Endpoint IN
Endpoint OUT
Class instance 0
Class instance 0

Figure - Multiple Class Instances - HS/FS Device (2 Configurations and 1 Single Interface)

The code corresponding to Figure - Multiple Class Instances - HS/FS Device (2 Configurations and 1 Single Interface) in the *Class Instance Concept* page is shown in Listing - Multiple Class Instances - HS/FS Device (2 Configurations and 1 Single Interface) in the *Class Instance Concept* page.

```
USBD_ERR    err;
CPU_INT08U  class_0;


USBD_XXXX_Init(&err);                                                                   (1)
if (err != USBD_ERR_NONE) {
    /* $$$$ Handle the error. */
}

class_0 = USBD_XXXX_Add(&err);                                                          (2)
if (err != USBD_ERR_NONE) {
    /* $$$$ Handle the error. */
}

USBD_XXXX_CfgAdd(class_0, dev_nbr, cfg_0_fs, &err);                                     (3)
if (err != USBD_ERR_NONE) {
    /* $$$$ Handle the error. */
}

USBD_XXXX_CfgAdd(class_0, dev_nbr, cfg_0_hs, &err);                                     (4)
if (err != USBD_ERR_NONE) {
    /* $$$$ Handle the error. */
}
```

Listing - Multiple Class Instances - HS/FS Device (2 Configurations and 1 Single Interface)

(1) Initialize the class. Any internal variables, structures, and class RTOS port will be

initialized.

(2) Create the class instance, `class_0`. The function `USBD_XXXX_Add()` allocates a class control structure associated to `class_0`. Depending on the class, besides the parameter for an error code, `USBD_XXXX_Add()` may have additional parameters representing class-specific information stored in the class control structure.

(3) Add the class instance, `class_0`, to the full-speed configuration, `cfg_0_fs`. `USBD_XXXX_CfgAdd()` will create the interface 0 and its associated endpoints IN and OUT. If the full-speed configuration is active, any communication done on the interface 0 will use the class instance number, `class_0`.

(4) Add the class instance, `class_0`, to the high-speed configuration, `cfg_0_hs`.

In the case of the high-speed capable device presented in Figure - Multiple Class Instances - HS/FS Device (2 Configurations and 1 Single Interface) in the *Class Instance Concept* page, in order to enable the use of *Device_Qualifier* and *Other_Speed_Configuration* descriptors, the function `USBD_CfgOtherSpeed()` should be called during the µC/USB-Device initialization. Listing - App_USBD_Init() Function in the *Running the Sample Application* page presents the function `App_USBD_Init()` defined in `app_usbd.c`. This function shows an example of the µC/USB-Device initialization sequence. `USBD_CfgOtherSpeed()` should be called after the creation of a high-speed and a full-speed configurations with `USBD_CfgAdd()`. Listing - Use of USBD_CfgOtherSpeed() in the *Class Instance Concept* page below shows the use of `USBD_CfgOtherSpeed()` based on Listing - App_USBD_Init() Function in the *Running the Sample Application* page. Error handling is omitted for clarity.

```
 CPU_BOOLEAN  App_USBD_Init (void)
{
    CPU_INT08U   dev_nbr;
    CPU_INT08U   cfg_0_fs;
    CPU_INT08U   cfg_0_hs;
    USBD_ERR     err;


    ...                                                                                  (1)

    if (USBD_DrvCfg_<controller>.Spd == USBD_DEV_SPD_HIGH) {

        cfg_0_hs = USBD_CfgAdd(dev_nbr,                                                  (2)
                                USBD_DEV_ATTRIB_SELF_POWERED,
                                100u,
                                USBD_DEV_SPD_HIGH,
                               "HS configuration",
                               &err);
    }
    cfg_0_fs = USBD_CfgAdd(dev_nbr,                                                      (3)
                            USBD_DEV_ATTRIB_SELF_POWERED,
                            100u,
                            USBD_DEV_SPD_FULL,
                           "FS configuration",
                           &err);

    USBD_CfgOtherSpeed(dev_nbr,                                                          (4)
                        cfg_0_hs,
                        cfg_0_fs,
                       &err);

    return (DEF_OK);
}
```

Listing - Use of USBD_CfgOtherSpeed()

(1) Refer to Listing - App_USBD_Init() Function in the *Running the Sample Application* page for the beginning of the initialization.

(2) Add the high-speed configuration, `cfg_0_hs`, to your high-speed capable device.

(3) Add the full-speed configuration, `cfg_0_fs`, to your high-speed capable device.

(4) Associate the high-speed configuration `cfg_0_hs` with its other-speed counterpart, `cfg_0_fs`.

Figure - Multiple Class Instances - FS Device (2 Configurations and Multiple Interfaces) in the *Class Instance Concept* page represents a more complex example. A full-speed device is composed of two configurations. The device has two functions which belong to the same class. Each function is described by two interfaces. Each interface has a pair of bidirectional endpoints. In this example, two class instances are created. Each class instance is associated with a group of interfaces as opposed to Figure - Multiple Class Instances - FS Device (1 Configuration with 1 Interface) in the *Class Instance Concept* page and Figure - Multiple Class Instances - HS/FS Device (2 Configurations and 1 Single Interface) in the *Class Instance Concept* page where the class instance was associated to a single interface.

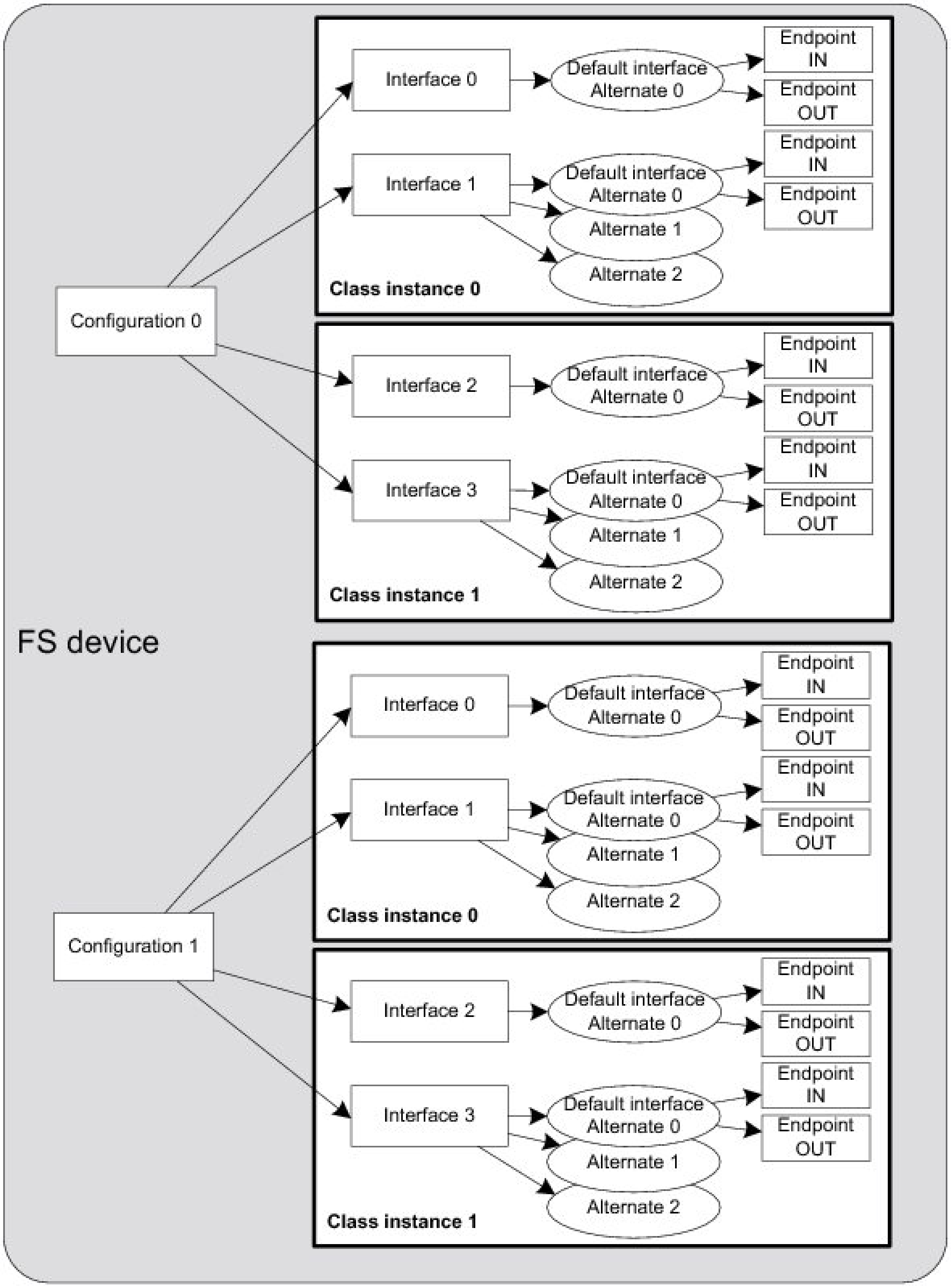


Figure - Multiple Class Instances - FS Device (2 Configurations and Multiple Interfaces)

The code corresponding to Figure - Multiple Class Instances - FS Device (2 Configurations and Multiple Interfaces) in the *Class Instance Concept* page is shown in Listing - Multiple Class Instances - FS Device (2 Configurations and Multiple Interfaces) in the *Class Instance Concept* page. The error handling is omitted for clarity.

```
USBD_ERR    err;
CPU_INT08U  class_0;
CPU_INT08U  class_1;


USBD_XXXX_Init(&err);                                                                    (1)

class_0 = USBD_XXXX_Add(&err);                                                           (2)
class_1 = USBD_XXXX_Add(&err);                                                           (3)

USBD_XXXX_CfgAdd(class_0, dev_nbr, cfg_0, &err);                                         (4)
USBD_XXXX_CfgAdd(class_1, dev_nbr, cfg_0, &err);                                         (5)

USBD_XXXX_CfgAdd(class_0, dev_nbr, cfg_1, &err);                                         (6)
USBD_XXXX_CfgAdd(class_1, dev_nbr, cfg_1, &err);                                         (6)
```

Listing - Multiple Class Instances - FS Device (2 Configurations and Multiple Interfaces)

(1) Initialize the class. Any internal variables, structures, and class RTOS port will be initialized.

(2) Create the class instance, `class_0`. The function `USBD_XXXX_Add()` allocates a class control structure associated to `class_0`.

(3) Create the class instance, `class_1`. The function `USBD_XXXX_Add()` allocates another class control structure associated to `class_1`.

(4) Add the class instance, `class_0`, to the configuration, `cfg_0`. `USBD_XXXX_CfgAdd()` will create the interface 0, interface 1, alternate interfaces, and the associated endpoints IN and OUT. The class instance number, `class_0`, will be used for any data communication on interface 0 or interface 1.

(5) Add the class instance, `class_1`, to the configuration, `cfg_0`. `USBD_XXXX_CfgAdd()` will create the interface 2, interface 3 and their associated endpoints IN and OUT. The class instance number, `class_1`, will be used for any data communication on interface 2 or interface 3.

(6) Add the same class instances, `class_0` and `class_1`, to the other configuration, `cfg_1`.

You can refer to the Configuration Examples page for some configuration examples showing multiple class instances applied to composite devices. Composite devices use at least two different classes provided by the µC/USB-Device stack. The Composite High Speed USB Device section gives a concrete example based on Figure - Multiple Class Instances - HS/FS Device (2 Configurations and 1 Single Interface) in the *Class Instance Concept* page. See the Complex Composite High Speed USB Device section for a hybrid example that corresponds to Figure - Multiple Class Instances - HS/FS Device (2 Configurations and 1 Single Interface) in the *Class Instance Concept* page and Figure - Multiple Class Instances - FS Device (2 Configurations and Multiple Interfaces) in the *Class Instance Concept* page.

Class Instance Structures

When a class instance is created, a control structure is allocated and associated to a specific class instance. The class uses this control structure for its internal operations. All the Micrium USB classes define a class control structure data type. Listing - Class Instance Control Structure in the *Class Instance Structures* page shows the declaration of such data structure.

```
struct usbd_xxxx_ctrl {
    CPU_INT08U        DevNbr;                                          (1)
    CPU_INT08U        ClassNbr;                                        (2)
    USBD_XXXX_STATE   State;                                           (3)
    USBD_XXXX_COMM   *CommPtr;                                         (4)
    ...                                                                (5)
};
```

Listing - Class Instance Control Structure

(1) The device number to which the class instance is associated with.

(2) The class instance number.

(3) The class instance state.

(4) A pointer to a class instance communication structure. This structure holds information regarding the interface’s endpoints used for data communication.

(5) Class-specific fields.

During the communication phase, the class communication structure is used by the class for data transfers on the endpoints. It allows you to route the transfer to the proper endpoint within the interface. There will be one class communication structure per configuration to which the class instance has been added. Listing - Class Instance Communication Structure in the *Class Instance Structures* page presents this structure.

```
struct usbd_xxxx_comm {
   USBD_XXXX_CTRL  *CtrlPtr;                                                (1)
   CPU_INT08U       ClassEpInAddr;                                          (2)
   CPU_INT08U       ClassEpOutAdd2;                                         (2)
    ...                                                                     (2)
};
```

Listing - Class Instance Communication Structure

(1) A pointer to the class instance control structure to which the communication relates to.

(2) Class-specific fields. In general, this structure stores mainly endpoint addresses related to the class. Depending on the class, the structure may store other types of information. For instance, the Mass Storage Class stores information about the Command Block and Status Wrappers.

Micrium's USB classes define a class state for each class instance created. The class state values are implemented in the form of an enumeration:

```
typedef  enum  usbd_xxxx_state {
    USBD_XXXX_STATE_NONE = 0,
    USBD_XXXX_STATE_INIT,
    USBD_XXXX_STATE_CFG
} USBD_XXXX_STATE;
```

Listing - Enumeration of Class State Values

Figure - Class State Machine in the *Class Instance Structures* page defines a class state machine which applies to all the Micrium classes. Three class states are used.

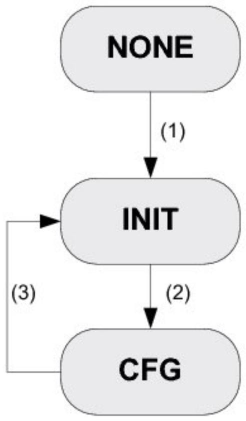


Figure - Class State Machine

(1) A class instance has been added to a configuration, the class instance state transitions to the ‘Init’ state. No data communication on the class endpoint(s) can occur yet.

(2) The host has sent the `SET_CONFIGURATION` request to activate a certain configuration. The Core layer calls a class callback informing about the completion of the standard enumeration. The class instance state transitions to the ‘Cfg’ state. This state indicates that the device has transitioned to the ‘Configured’ state defined by the Universal Serial Bus Specification revision 2.0. The data communication may begin. Some classes such as the MSC class may require that the host sends some class-specific requests before the communication on the endpoints really starts.

(3) The Core layer calls another class callback informing that the host has sent a `SET_CONFIGURATION` request with a new configuration number or with the value 0 indicating a configuration reset, or that the device has been physically disconnected from the host. In all these cases, the current active configuration becomes inactive. The class instance state transitions to the ‘Init’ state. Any ongoing transfers on the endpoints managed by the class instance have been aborted by the Core layer. No more communication is possible until the host sends a new `SET_CONFIGURATION` request with a non-null value or until the device is plugged again to the host.

Class and Core Layers Interaction Through Callbacks

Upon reception of standard, class-specific and/or vendor requests, the Core layer can notify the Class layer about the event associated with the request via the use of class callbacks. Each Micrium class must define a class callbacks structure of type `USBD_CLASS_DRV` that contains function pointers. Each callback allows the class to perform a specific action if it is required. Listing - Class Callback Structure in the *Class and Core Layers Interaction Through Callbacks* page shows a generic example of class callback structure. In the listing, `XXXX` could be replaced with `Audio`, `CDC, HID, MSC, PHDC` or `Vendor`.

```
static USBD_CLASS_DRV USBD_XXXX_Drv = {
    USBD_XXXX_Conn,                                                        (1)
    USBD_XXXX_Disconn,                                                     (2)
    USBD_XXXX_AltSettingUpdate,                                            (3)
    USBD_XXXX_EP_StateUpdate,                                              (4)
    USBD_XXXX_IF_Desc,                                                     (5)
    USBD_XXXX_IF_DescSizeGet,                                              (6)
    USBD_XXXX_EP_Desc,                                                     (7)
    USBD_XXXX_EP_DescSizeGet,                                              (8)
    USBD_XXXX_IF_Req,                                                      (9)
    USBD_XXXX_ClassReq,                                                   (10)
    USBD_XXXX_VendorReq,                                                  (11)
#if (USBD_CFG_MS_OS_DESC_EN == DEF_ENABLED)
    USBD_XXXX_MS_GetCompatID,                                             (12)
    USBD_XXXX_MS_GetExtPropertyTbl,                                       (13)
#endif
};
```

Listing - Class Callback Structure

(1) Notify the class that a configuration has been activated.

(2) Notify the class that a configuration has been deactivated.

(3) Notify the class that an alternate interface setting has been updated.

(4) Notify the class that an endpoint state has been updated by the host. The state is generally stalled or not stalled.

(5) Ask the class to build the interface class-specific descriptors.

(6) Ask the class for the total size of interface class-specific descriptors.

(7) Ask the class to build endpoint class-specific descriptors.

(8) Ask the class for the total size of endpoint class-specific descriptors.

(9) Ask the class to process a standard request whose recipient is an interface.

(10) Ask the class to process a class-specific request.

(11) Ask the class to process a vendor-specific request.

(12) Ask the class to provide the Microsoft Compatible ID and Subcompatible ID for this interface. This callback must not be defined when `USBD_CFG_MS_OS_DESC_EN` is set to `DEF_DISABLED`.

(13) Ask the class to provide a table of Microsoft Extended properties for this interface. This callback must not be defined when `USBD_CFG_MS_OS_DESC_EN` is set to `DEF_DISABLED`.

A class is not required to provide all the callbacks. If a class for instance does not define alternate interface settings and does not process any vendor requests, the corresponding function pointer will be a null-pointer. Listing - Class Callback Structure with Null Function Pointers in the *Class and Core Layers Interaction Through Callbacks* page presents the callback structure for that case.

```
static  USBD_CLASS_DRV  USBD_XXXX_Drv = {
    USBD_XXXX_Conn,
    USBD_XXXX_Disconn,
    0,
    USBD_XXXX_EP_StateUpdate,
    USBD_XXXX_IF_Desc,
    USBD_XXXX_IF_DescSizeGet,
    USBD_XXXX_EP_Desc,
    USBD_XXXX_EP_DescSizeGet,
    USBD_XXXX_IF_Req,
    USBD_XXXX_ClassReq,
    0,
#if (USBD_CFG_MS_OS_DESC_EN == DEF_ENABLED)
    0,
    0,
#endif
};
```

Listing - Class Callback Structure with Null Function Pointers

If a class is composed of one interface then one class callback structure is required. If a class is composed of several interfaces then the class may define several class callback structures. In that case, a callback structure may be linked to one or several interfaces. For instance, the Communication Device Class (CDC) is composed of one Communication Interface and one or more Data Interfaces. The Communication interface will be linked to a callback structure. The Data interfaces may be linked to another callback structure common to all Data interfaces.

The class callbacks are called by the core task when receiving a request from the host sent over control endpoints (refer to the Task Model page for more details on the core task). Table - Class Callbacks and Requests Mapping in the *Class and Core Layers Interaction Through Callbacks* page indicates which callbacks are mandatory and optional and upon reception of which request the core task calls a specific callback.

Request type	Callback	Request	Mandatory? / Note
Standard	`Conn()`	`SET_CONFIGURATION`	Yes / Host selects a non-null configuration number.
Standard	`Disconn()`	`SET_CONFIGURATION`	Yes / Host resets the current configuration or device physically detached from host.
Standard	`AltSettingUpdate()`	`SET_INTERFACE`	No / Callback skipped if no alternate settings are defined for one or more interfaces.
Standard	`EP_StateUpdate()`	`SET_FEATURE` `CLEAR_FEATURE`	No / Callback skipped if the state of the endpoint is not used.
Standard	`IF_Desc()`	`GET_DESCRIPTOR`	No / Callback skipped if no class-specific descriptors for one or more interfaces.
Standard	`IF_DescSizeGet()`	`GET_DESCRIPTOR`	No / Callback skipped if no class-specific descriptors for one or more interfaces.
Standard	`EP_Desc()`	`GET_DESCRIPTOR`	No / Callback skipped if no class-specific descriptors for one or more endpoints.
Standard	`EP_DescSizeGet()`	`GET_DESCRIPTOR`	No / Callback skipped if no class-specific descriptors for one or more endpoints.
Standard	`IF_Req()`	`GET_DESCRIPTOR`	No / Callback skipped if no standard descriptors provided by a class.
Class	`ClassReq()`	-	No / Callback skipped if no class-specific requests defined by the class specification.
Vendor	`VendorReq()`	-	No / Callback skipped if no vendor requests.
Microsoft	`MS_GetCompatID()`	`GET_MS_DESCRIPTOR`	No / Callback skipped if no Microsoft compatible ID required.
Microsoft	`MS_GetExtPropertyTbl()`	`GET_MS_DESCRIPTOR`	No / Callback skipped if no Microsoft Extended properties required.

Table - Class Callbacks and Requests Mapping

Audio Class

This section describes the audio class supported by C/USB-Device. The Audio class implementation complies with the following specifications:

- *USB Device Class Definition for Audio Devices, Release 1.0, March 18, 1998.*
- *USB Device Class Definition for Terminal Types, Release 1.0, March 18, 1998.*
- *USB Device Class Definition for Audio Data Formats, Release 1.0, March 18, 1998.*

The audio class allows to build devices that manipulate music, voice and other sound types. The data manipulation involves the audio data itself (i.e. encoded stream) and the environment's controls in which the stream will be employed. An audio device rarely forms a single USB device. In many cases, audio functions exist with other functions to create a composite device. A composite device that embeds audio and another function could be a high-end webcam (audio + video functions), an headset with direct stream controls on it such as volume, mute buttons (audio + human interface functions), a portable USB Blu-ray driver (audio + video + data storage functions), etc. Adding audio capabilities to a USB device is available through two distinct specifications: audio 1.0 and 2.0. Version 1.0 released in 1998 was designed exclusively for full-speed audio devices. Audio 1.0 allows you to transport encoded audio data through isochronous endpoints and MIDI data streams over bulk endpoints. In 2006, version 2.0 was released to address the need for high-speed devices for the professional audio market. Audio 2.0 specification extends the audio 1.0 specification by adding full support for high-speed operations. Thus, more bandwidth is available for high bit rate multiple channels audio applications. Version 2.0 enhances capabilities, controls and notifications of units and terminals. Nowadays, audio 1.0 is still very popular for the general consumer audio market (e.g. headset, speaker, microphone). All major operating systems (Microsoft Windows, Apple Mac OS, Linux) support audio 1.0 devices by providing a native audio 1.0 driver. Audio 2.0 is only natively supported by Apple Mac OS and Linux.

As Micrium audio class supports only audio 1.0 specification, the rest of this section does not mention audio 2.0 anymore.

Audio Class Overview

This section presents the keys characteristics of audio 1.0 specification that should be understood to use Micriµm audio class. Note that MIDI interface is mentioned in this section but it is not supported by the current audio class implementation. MIDI is referred to better understand the audio 1.0 device in its entirety.

Functional Characteristics

An audio device is composed of one or several Audio Interface Collection (AIC). Each AIC describes one unique audio function. Thus, if the audio device has several audio functions, it means that several AIC can be active at the same time. An AIC is formed by:

- One mandatory AudioControl (AC) interface
- Zero or several optional AudioStreaming (AS) interfaces
- Zero or several optional MIDI interfaces

Figure - Audio Function Global View in the *Audio Class Overview* page presents a typical composite audio device:

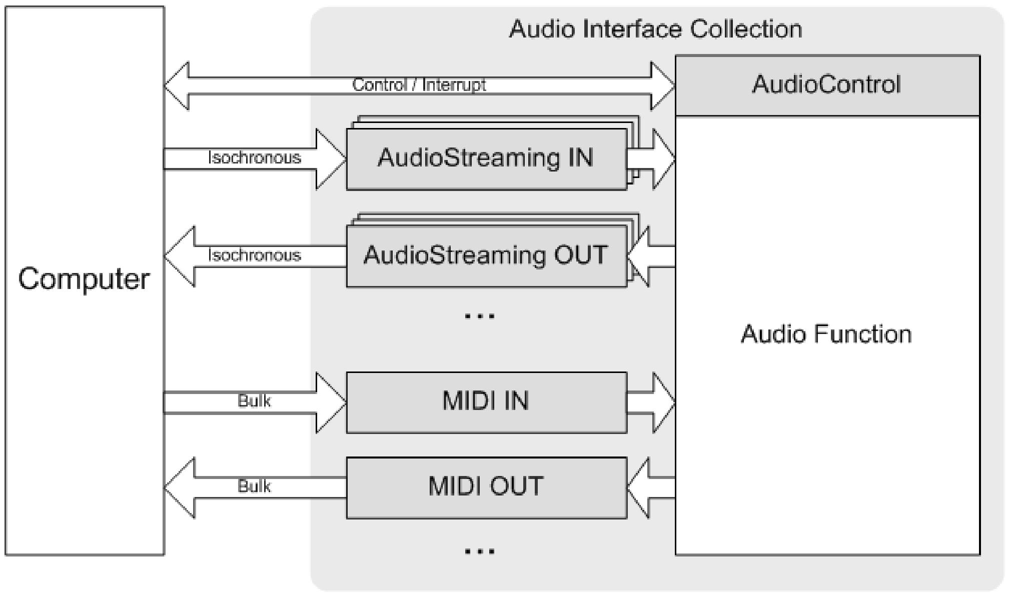


Figure - Audio Function Global View

An AC interface is used to control and configure the audio function before and while playing a stream. For instance, AC allows to mute, change the volume, control tones (bass, mid, treble), select a certain path within the device to play the stream, mix streams, etc. It uses several class-specific requests to control and configure the audio function. An AS interface transports audio data via isochronous endpoints into and out of the function. An audio stream can be configured by using certain class-specific requests sent to the AS interface.
The available configuration is the sampling frequency and/or the pitch. A MIDI interface carries MIDI data via bulk endpoints.

An audio function has the following endpoints characteristics:

- One pair of control IN and OUT endpoints called the default endpoint.
- One optional interrupt IN endpoint.
- One or several isochronous IN and/or OUT endpoints (mandatory only if at least one AS interface is used).
- One or several bulk IN and/or OUT endpoints (mandatory only if at least one MIDI interface is used).

Table - Audio Class Endpoints Usage in the *Audio Class Overview* page describes the usage of the different endpoints:

Endpoint	**Direction**	**Usage**	**Associated to Interface**
Control IN	Device-to-host	Standard requests for enumeration and class-specific requests.	AC, AS
Control OUT	Host-to-device	Standard requests for enumeration, class-specific requests.	AC, AS
Interrupt IN	Device-to-host	Status about different addressable entities (terminals, units, interfaces and endpoints) inside the audio function.	AC
Isochronous IN	Device-to-host	Record stream communication.	AS
Isochronous OUT	Host-to-device	Playback stream communication.	AS
Bulk IN	Device-to-host	Record stream communication.	MIDI
Bulk OUT	Host-to-device	Playback stream communication.	MIDI

Table - Audio Class Endpoints Usage

Besides the standard enumeration process, control endpoints can be used to configure all terminals and units. Terminals and units are described in the next section Audio Function Topology. The interrupt IN endpoint is used to retrieve general status about any addressable entities. It is associated to the additional class-specific requests: Memory and Status requests. In practice, the interrupt IN endpoint is rarely implemented in audio 1.0 devices because Memory and Status requests are almost never used.

AS interfaces use isochronous endpoints to transfer audio data. Isochronous transfers were designed to deliver *real-time* data between host and device with a guaranteed latency. The host allocates a specific amount of bandwidth within a frame (i.e. 1 ms) for isochronous transfers. These ones have priority over control, and bulk. Hence, isochronous are well-adapted to audio data streaming. An audio device moving data through USB operates in a system where different clocks are running (audio sample clock, USB bus clock and service clock. Refer to section 5.12.2 of USB 2.0 specification for more details about these clocks). These three clocks must be synchronized at some point in order to deliver reliably isochronous data. Otherwise, clock synchronization issues (for instance, clock drift, jitter, clock-to-clock phase differences) may introduce unwanted audio artifacts.These clock synchronization issues are a one of the major challenges when streaming audio data between the host and the device. In order to take up this challenge, USB 2.0 specification proposes a strong synchronization scheme to deliver isochronous data. There are three types of synchronization:

- **Asynchronous:** endpoint produces and consumes data at a rate that is locked either to a clock external to the USB or to a free-running internal clock. The data rate can be either fixed, limited to a certain number of sampling frequencies or continuously programmable. Asynchronous endpoints cannot synchronize to Start-of-Frame (SOF) or any other clock in the USB domain.

- **Synchronous:** endpoint can have its clock system controlled externally through SOF synchronization. The hardware must provide a way to slave the sample clock of the audio part to the 1 ms SOF tick of the USB part to have a perfect synchronization. Synchronous endpoints may produce or consume isochronous data streams at either a fixed, a limited number or a continuously programmable data rate.

- **Adaptive:** endpoint is the most capable because it can produce and consume at any rate within their operating range.

Refer to section '5.12.4.1 Synchronization Type' of USB 2.0 specification for more details about synchronization types.

An AS interface must have at least **two alternate setting** interfaces:

- One default interface declaring 0 endpoint. This interface is used by the host to temporarily relinquish USB bandwidth if the stream on this AS interface is not active.

- One or several other alternate setting interfaces with at least one isochronous endpoint. These alternate settings are called operational interfaces, that is the stream is active. Every alternate setting represents the same AS interface but with the associated isochronous endpoint having a different characteristic (e.g. maximum packet size). When opening a stream, the host must select only one operational interface. The selection is based on the available resources the host can allocate for this endpoint.

Audio Function Topology

An audio function is composed of **units** and **terminals.** Units and terminals form addressable entities allowing to manipulate the physical properties of the audio function. Figure - Example of Audio Function Topology in the *Audio Class Overview* page shows an example of audio function topology with some units and terminals:

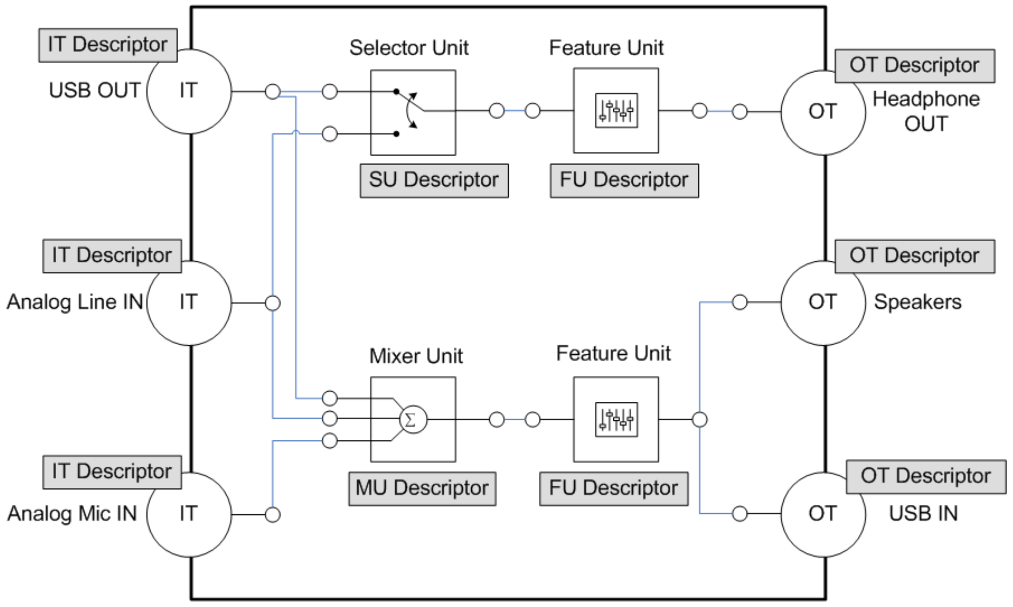


Figure - Example of Audio Function Topology

A unit is the basic building block of an audio function. Connected together, units allow to fully describe most audio functions. A unit has one or more Input pins and one single Output pin. Each pin represents a cluster of logical audio channels inside the audio function. A unit model can be crossed by an information that is of a digital nature, fully analog or even hybrid audio functions. Each unit has an **associated descriptor** with several fields to identify and characterize the unit. Audio 1.0 defines five units presented in Table - Units and Terminals Description, Controls and Requests in the *Audio Class Overview* page.

A terminal is an entity that represents a starting or ending point for audio channels inside the audio function. There are two types of terminal presented in table Table - Units and Terminals Description, Controls and Requests in the *Audio Class Overview* page: **Input** and **Output** terminals. A terminal either provides data streams to the audio function (Input Terminal) or consumes data streams coming from the audio function (Output Terminal). Each terminal has an **associated descriptor**.

The functionality represented by a unit or a terminal is managed through audio **controls**. A control gives access to a specific audio property (e.g. volume, mute). A control is managed by using class-specific requests with the default control endpoint. Class-specific requests for a unit or terminal's control are addressed for the **AC** interface. A control has a set of attributes that can be manipulated or that present additional information on the behavior of the control. The possible attributes are:

- Current setting attribute (CUR)
- Minimum setting attribute (MIN)
- Maximum setting attribute (MAX)
- Resolution attribute (RES)
- Memory space attribute (MEM)

The class-specific requests are GET and SET requests whose general structure is shown in Table - Class-Specific Requests General Structure in the *Audio Class Overview* page.

Entity	Description	Control	Request Supported
Input Terminal (IT)	Interface between the audio function's 'outside world' and other units in the audio function. Refer to section '3.5.1 Input Terminal' of audio 1.0 specification for more details.	Copy Protect	GET_CUR
Output Terminal (OT)	Interface between units inside the audio function and the 'outside world'. Refer to section '3.5.2 Output Terminal ' of audio 1.0 specification for more details.	Copy Protect	SET_CUR
Mixer Unit (MU)	Transforms a number of logical input channels into a number of logical output channels. Refer to section '3.5.3 Mixer Unit ' of audio 1.0 specification for more details.	Input channel to mix	SET_CUR and GET_CUR/MIN/MAX/RES
Selector Unit (SU)	Selects from n audio channel clusters, each containing m logical input channels and routes them unaltered to the single output audio channel cluster, containing m output channels. Refer to section '3.5.4 Selector Unit ' of audio 1.0 specification for more details.	Input pin selection	SET/GET_CUR
Feature Unit (FU)	Multi-channel processing unit that provides basic manipulation of the incoming logical channels. Refer to section '3.5.5 Feature Unit ' of audio 1.0 specification for more details.	Mute	SET/GET_CUR
		Volume	SET_CUR and GET_CUR/MIN/MAX/RES
		Bass	SET_CUR and GET_CUR/MIN/MAX/RES
		Mid	SET_CUR and GET_CUR/MIN/MAX/RES
		Treble	SET_CUR and GET_CUR/MIN/MAX/RES
		Graphic Equalizer	SET_CUR and GET_CUR/MIN/MAX/RES
		Automatic Gain	SET/GET_CUR
		Delay	SET_CUR and GET_CUR/MIN/MAX/RES
		Bass Boost	SET_CUR and GET_CUR/MIN/MAX/RES
		Loudness	SET/GET_CUR
Processor Unit (PU)	Transforms a number of logical input channels, grouped into one or more audio channel clusters into a number of logical output channels, grouped into one audio channel cluster by applying a certain algorithms:	Enable	SET/GET_CUR
		Mode Select	SET_CUR and GET_CUR/MIN/MAX/RES

	• Up/Down-mix • Dolby Prologic • 3D-Stereo Extender • Reverberation • Chorus • DynamicRangeCompressor Refer to section '3.5.6 Processor Unit' of audio 1.0 specification for more details.	Spaciousness	SET_CUR and GET_CUR/MIN/MAX/RES
		Reverberation Type	SET_CUR and GET_CUR/MIN/MAX/RES
		Reverberation Level	SET_CUR and GET_CUR/MIN/MAX/RES
		Reverberation Time	SET_CUR and GET_CUR/MIN/MAX/RES
		Reverberation Feedback	SET_CUR and GET_CUR/MIN/MAX/RES
		Chorus Level	SET_CUR and GET_CUR/MIN/MAX/RES
		Chorus Rate	SET_CUR and GET_CUR/MIN/MAX/RES
		Chorus Depth	SET_CUR and GET_CUR/MIN/MAX/RES
		Compression Ratio	SET_CUR and GET_CUR/MIN/MAX/RES
		Max Amplitude	SET_CUR and GET_CUR/MIN/MAX/RES
		Threshold	SET_CUR and GET_CUR/MIN/MAX/RES
		Attack TIme	SET_CUR and GET_CUR/MIN/MAX/RES
		Release Time	SET_CUR and GET_CUR/MIN/MAX/RES
Extension Unit (XU)	Allows to add a vendor-specific unit. Refer to section '3.5.7 Extension Unit' of audio 1.0 specification for more details.	Enable	SET/GET_CUR

Table - Units and Terminals Description, Controls and Requests

Request	Attribute	Recipient
SET_XXX	Current (CUR) Minimum (MIN) Maximum (MAX) Resolution (RES) Memory space (MEM)	AC interface AS interface Isochronous endpoint
GET_XXX	Current (CUR) Minimum (MIN) Maximum (MAX) Resolution (RES) Memory space (MEM)	AC interface AS interface Isochronous endpoint

Table - Class-Specific Requests General Structure

As shown in Table - Class-Specific Requests General Structure in the *Audio Class Overview* page, there are also class-specific requests addressed to **AS** interface or **isochronous endpoint** permitting to manage some other controls. These controls are presented in Table - AudioStreaming Interface Controls and Requests in the *Audio Class Overview* page.

Recipient	Control	Request supported
AS Interface	Depends of Audio Data Format	Depends of Audio Data Format
Endpoint	Sampling Frequency	SET_CUR and GET_CUR/MIN/MAX/RES
Endpoint	Pitch	SET/GET_CUR

Table - AudioStreaming Interface Controls and Requests

Units and terminals descriptors allows the USB audio device to describe the audio function topology. By retrieving these descriptors, the host is able to rebuild the audio function topology because the interconnection between units and terminals are fully defined. Units and terminals descriptors form **class-specific descriptors** associated to the AC interface. There are also class-specific descriptors associated to AS interface and its associated isochronous endpoint (refer to audio 1.0 specification, section 4 '*Descriptors*' for more details about AC and AS class-specific descriptors and their content). These AS class-specific descriptors gives details about the audio data format manipulated by the AS interface. The audio 1.0 specification defines three audio data formats which encompass some uncompressed and compressed audio formats:

Type I format

- PCM
- PCM8
- IEEE_Float
- ALaw and μLaw

Type II format

- MPEG
- AC-3

Type III format based on IEC1937 standard

Refer to Audio 1.0 Data Formats specification, section 2 '*Audio Data Formats*' for more details about these formats.

Feedback Endpoint

The USB 2.0 specification states that if isochronous OUT data endpoint uses the asynchronous synchronization, an isochronous feedback endpoint is needed. The feedback endpoint allows the device to slow down or speed up the rate at which the host sends audio samples per frame so that USB and audio clocks are always in sync. A few interesting characteristics of the feedback endpoint are:

- Initially known as feedback endpoint, the USB 2.0 specification has replaced the name of feedback endpoint by Synch endpoint.
- Feedback endpoint is always in the opposite direction of isochronous data endpoint.
- Feedback endpoint is defined by a refresh period, period at which the host asks for the feedback value (Ff).
- An extended standard endpoint descriptor is used to describe the association between a data endpoint and its feedback endpoint. The fields part of the extension are:
    - *bSynchAddress:* The address of the endpoint used to communicate synchronization information if required by this endpoint. Reset to zero if no synchronization pipe is used.
    - *bRefresh:* This field indicates the rate at which an isochronous synchronization pipe provides new synchronization feedback data. This rate must be a power of 2, therefore only the power is reported back and the range of this field is from 1 (2 ms) to 9 (512 ms).
- Ff is expressed in number of samples per (micro)frame for one channel. The Ff value consists of:
    - an **integer** part that represents the (integer) number of samples per (micro)frame and,

- a **fractional part** that represents the “fraction” of a sample that would be needed to match the sampling frequency Fs to a resolution of 1 Hz or better.

There are 2 different Ff encoding depending of the device speed.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10
FS: Unsigned encoding. 3 bytes are needed. Lower optional 4 bits used to extend precision of Ff, otherwise 0.																					
0	0	0	0	0	0	0	0	Nbr of samples per frame for one channel										Fraction of a sample			
HS: Unsigned encoding. 3 bytes are needed. Lower optional 3 bits used to extend precision of Ff, otherwise 0.																					
0	0	0	0	Nbr of samples per µframe for one channel												Fraction of a sample					

Full-speed encoding is called format 10.10 (without fraction extension) or 10.14 (with fraction extension).

Full-speed encoding is called format 12.13 (without fraction extension) or 16.16 (with fraction extension).

Refer to USB 2.0 specification, section 5.12.4.2 '*Feedback*' for more details about the feedback endpoint.

Audio Class Features Support

As there are many features available from audio 1.0 specification to build an audio device, this section starts by clearly listing what the Micrium Audio class supports and does not support:

Supported	NOT Supported

• Synchronization type
  ◦ Asynchronous
  ◦ Synchronous
  ◦ Adaptive
• Synch endpoint for asynchronous sink (Isochronous OUT)
• Audio addressable entities and their associated descriptors
  ◦ Input Terminal
  ◦ Output Terminal
  ◦ Mixer Unit
  ◦ Selector Unit
  ◦ Feature Unit
• Audio Class-Specific Requests
  ◦ SET_ CUR
  ◦ SET_ MIN
  ◦ SET_ MAX
  ◦ SET_ RES
  ◦ GET_ CUR
  ◦ GET_ MIN
  ◦ GET_ MAX
  ◦ GET_ RES
• Terminal Control: Copy Protect Control
• Feature Unit Controls
  ◦ Volume
  ◦ Mute
  ◦ Tone Control (Bass, Mid, Treble)
  ◦ Graphic Equalizer
  ◦ Automatic Gain Control
  ◦ Delay
  ◦ Bass Boost
  ◦ Loudness
• Endpoint Controls
  ◦ Sampling frequency
  ◦ Pitch
	• MIDI specification
	• Synch endpoint for adaptive source (Isochronous IN)
	• Associated interfaces
	• Audio addressable entities:
	  ◦ Processing Unit
	  ◦ Extension Unit
	• Audio Class-Specific Requests
	  ◦ SET_MEM
	  ◦ GET_ MEM
	  ◦ GET_STAT
	• Data format
	  ◦ Type I (IEEE_FLOAT, ALaw, µLaw)
	  ◦ Type II (MPEG, AC-3)
	  ◦ Type III based on IEC1937 standard

• Data format • Type I • Format: PCM, PCM8 • Bit resolution: 8, 16, 24 or 32 bits • Sampling frequency: 11.025, 22.050, 32, 44.1, 48 and 96 kHz	

Table - Audio Class Features Support

Audio Class Architecture

Figure - General Architecture between a Host and Micrium's Audio Class in the *Audio Class Architecture* page shows the general architecture between the host and the Micrium audio class.

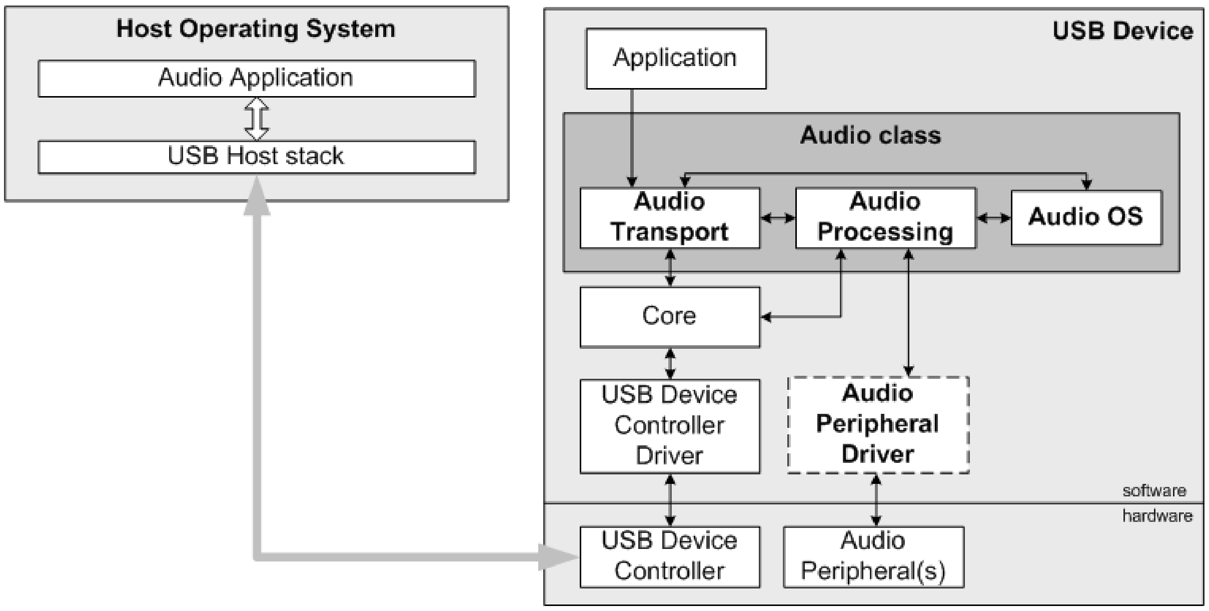


Figure - General Architecture between a Host and Micrium's Audio Class

The audio class is composed of three modules. The **Audio Transport** module is responsible for the initialization of the class done by the device application. It provides the class-specific descriptors needed by the host during the enumeration and also performs the class-specific requests decoding sent via control endpoints. The **Audio Processing** module is in charge of the the class-specific requests execution and the audio data streams communication done through isochronous endpoints. The **Audio OS** module provides specific OS services needed by the audio data streams communication. This module does not assume a particular OS. By default, Micriµm provides the Audio OS layer for µC/OS-II and µC/OS-III. If you need to port the audio class to your own OS, refer to Porting the Audio Class to an RTOS for more details about the Audio OS module.

Audio Peripheral Driver

This module communicates with the Audio Processing module to perform the final action associated to a class request (e.g. muting, changing the volume value) and to transfer audio data to/from the audio peripherals. Micrium provides a template of the Audio Peripheral Driver than can be used to start writing your driver for your audio codec. You can refer to Audio Peripheral Driver Guide for more details about how to write your codec driver. Micrium does NOT develop audio codec drivers. It is your responsibility to develop an Audio Peripheral Driver for your audio hardware.

The host can use various class-specific requests to configure and monitor terminals, units and streams. Any class-specific requests are sent through the control endpoints. Figure - Class-Specific Requests Management in the *Audio Class Architecture* page shows the class-specific requests management done by the audio class:

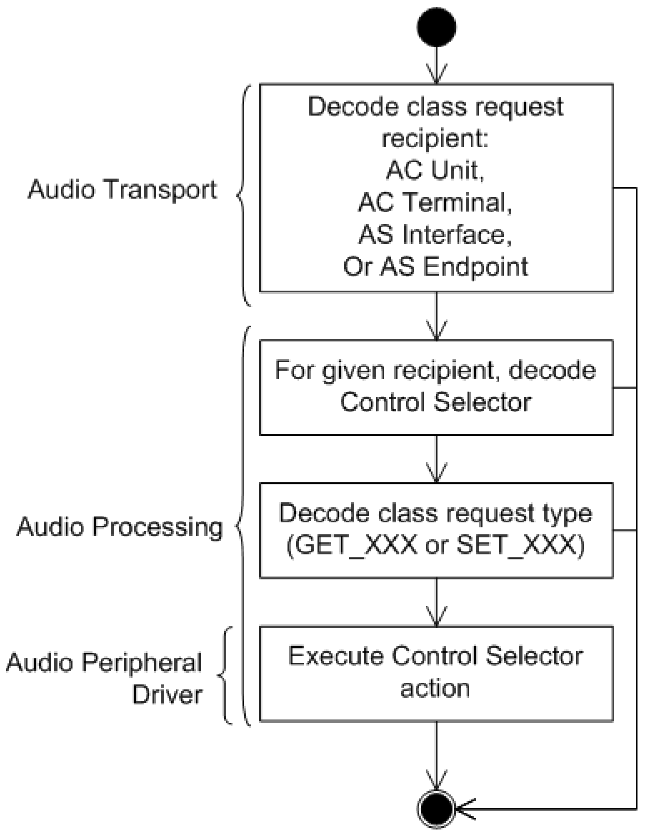

Audio Transport
Decode class request recipient: AC Unit, AC Terminal, AS Interface, Or AS Endpoint
Audio Processing
For given recipient, decode Control Selector
Decode class request type (GET_XXX or SET_XXX)
Audio Peripheral Driver
Execute Control Selector action

Figure - Class-Specific Requests Management

The Audio Transport module receives the class-specific request and does the first pass of decoding, that is determining the recipient: unit or terminal associated to the AudioControl interface or AudioStreaming interface or endpoint. Once the recipient identified, the Audio Processing is called and the control selector (that is the Control described in Table - Units and Terminals Description, Controls and Requests in the *Audio Class Overview* page and Table - AudioStreaming Interface Controls and Requests in the *Audio Class Overview* page) will be decoded. Note that a second recipient decoding among units (Feature, Mixer or Selector) and terminals (Input or Output) will be done. Once the control selector recognized, the request type supported by the control is verified. If the request is supported, the action associated is executed by the Audio Processing or the Audio Peripheral Driver if it requires access to the codec to get or set the information. At any steps, if something wrong is detected, the decoding process is aborted and the control transfer will be stalled by the device stack.

Audio Class Configuration

General Configuration

Some constants are available to customize the class. These constants are located in the USB device configuration file, `usbd_cfg.h` . Table - Audio Class Configuration Constants in the *Audio Class Configuration* page shows their description.

Constant	Description	Possible Values
`USBD_AUDIO_CFG_PLAYBACK_EN`	Enables or disables playback.	**`DEF_ENABLED`** or `DEF_DISABLED`
`USBD_AUDIO_CFG_RECORD_EN`	Enables or disables record. `USBD_AUDIO_CFG_PLAYBACK_EN` and `USBD_AUDIO_CFG_RECORD_EN` can be `DEF_DISABLED` at the same time. In that case, only the AudioControl interface is active. No AudioStreaming interface can be defined. It may be useful to configure an audio device which does not interact with the host through USB for audio streaming.	**`DEF_ENABLED`** or `DEF_DISABLED`
`USBD_AUDIO_CFG_FU_MAX_CTRL`	Enables all Feature Unit controls or disables all optional controls. When disabled, only the mute and volume controls are kept.	`DEF_ENABLED` or **`DEF_DISABLED`**
`USBD_AUDIO_CFG_MAX_NBR_AIC`	Configures the maximum number of class instances. Unless you plan on having multiple configurations or interfaces using different class instances, this can be set to 1.	From 1 to 254. Default value is **1** .
`USBD_AUDIO_CFG_MAX_NBR_CFG`	Configures the maximum number of configurations in which audio class is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed.	From 1 (full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_AUDIO_CFG_MAX_NBR_IT`	Configures the maximum number of input terminals.	From 1 to 255. Default value is **2**.
`USBD_AUDIO_CFG_MAX_NBR_OT`	Configures the maximum number of output terminals.	From 1 to 255. Default value is **2** .
`USBD_AUDIO_CFG_MAX_NBR_FU`	Configures the maximum number of feature units.	From 1 to 255. Default value is **2** .
`USBD_AUDIO_CFG_MAX_NBR_MU`	Configures the maximum number of mixer units. A Mixer Unit is optional.	From 0 to 255. Default value is **0** .
`USBD_AUDIO_CFG_MAX_NBR_SU`	Configures the maximum number of selector units. A Selector Unit is optional.	From 0 to 255. Default value is **0** .
`USBD_AUDIO_CFG_MAX_NBR_AS_IF_PLAYBACK`	Configures the maximum number of playback AudioStreaming interfaces per class instance.	From 1 to 255. Default value is **1** .
`USBD_AUDIO_CFG_MAX_NBR_AS_IF_RECORD`	Configures the maximum number of record AudioStreaming interfaces per class instance.	From 1 to 255. Default value is **1** .

`USBD_AUDIO_CFG_MAX_NBR_IF_ALT`	Configures the maximum number of operational alternate setting interfaces per AudioStreaming interface.	From 1 to 255. Default value is **2** .
`USBD_AUDIO_CFG_CLASS_REQ_MAX_LEN`	Configures the maximum class-specific request playload length in bytes. Among all class-specific requests supported by Audio 1.0 class, the Graphic Equalizer control of the Feature Unit use the longest payload size for the SET_CUR request. The payload for the Graphic Equalizer control can take up to 34 bytes depending of the number of frequency bands present. If the Graphical Equalizer control is not used by any feature unit, this constant can be set to 4. Refer to audio 1.0 specification, Table 5-27 for more details about Graphic Equalizer control.	From 1 to 34. Default value is **4** .
`USBD_AUDIO_CFG_BUF_ALIGN_OCTETS`	Configures the alignment in octets that audio buffers allocated for each AudioStreaming interface will use. The alignment is dependent of the peripheral used to move data between the memory and the audio peripheral. Note that this buffer alignment should be a multiple of the internal stack's buffer alignment set with the constant `USBD_CFG_BUF_ALIGN_OCTETS` as the audio buffers are passed to the USB device controller that can also have its alignment requirement. If your platform does not require buffer alignment, this should be set to `USBD_AUDIO_CFG_BUF_ALIGN_OCTETS`. If the CPU cache is used with the audio buffers, `USBD_AUDIO_CFG_BUF_ALIGN_OCTETS` should also take into account the cache line size requirement. To sum up, the value of `USBD_AUDIO_CFG_BUF_ALIGN_OCTETS` is influenced by: • Audio peripheral alignment requirement • USB device controller alignment requirement • Cache alignment requirement If all above requirements must be taken into account, `USBD_AUDIO_CFG_BUF_ALIGN_OCTETS` will be the worst case among all alignment requirements.	Typically 1, 2, 4 or 8. Default value is **`USBD_CFG_BUF_ALIGN_OCTETS`** .

`USBD_AUDIO_CFG_PLAYBACK_FEEDBACK_EN`	Enables or disables the playback feedback support. If an isochronous OUT endpoint using the asynchronous synchronization is associated to an AudioStreaming interface, you need to set `DEF_ENABLED` to enable the feedback support. Refer to section Playback Feedback Correction for more details about the audio feedback.	`DEF_ENABLED` or **`DEF_DISABLED`**
`USBD_AUDIO_CFG_PLAYBACK_CORR_EN`	Enables or disables built-in playback stream correction.	`DEF_ENABLED` or **`DEF_DISABLED`**
`USBD_AUDIO_CFG_RECORD_CORR_EN`	Enables or disables built-in record stream correction.	`DEF_ENABLED` or **`DEF_DISABLED`**
`USBD_AUDIO_CFG_STAT_EN`	Enables or disables audio statistics for playback and record.	`DEF_ENABLED` or **`DEF_DISABLED`**

Table - Audio Class Configuration Constants

The audio class uses two internal tasks to manage playback and record streams. The task priority and stack size shown in Table - Audio Internal Tasks' Configuration Constants in the *Audio Class Configuration* page are defined in the application configuration file, `app_cfg.h`. Refer to section Audio Class Stream Data Flow for more details about the audio internal tasks.

Constant	Description	Possible Values
`USBD_AUDIO_CFG_OS_PLAYBACK_TASK_PRIO`	Configures the priority of the audio playback task.	From the lowest to the highest priority supported by the OS used.
`USBD_AUDIO_CFG_OS_RECORD_TASK_STK_SIZE`	Configures the stack size of the audio playback task. The required size of the stack can greatly vary depending on the OS used, the CPU architecture, the type of application, etc. Refer to the documentation of the OS for more details about tasks and stack size calculation.	From the minimal to the maximal stack size supported by the OS used. The default value can be set for instance to **512**.
`USBD_AUDIO_CFG_OS_RECORD_TASK_PRIO`	Configures the priority of the audio record task.	From the lowest to the highest priority supported by the OS used.
`USBD_AUDIO_CFG_OS_PLAYBACK_TASK_STK_SIZE`	Configures the stack size of the audio record task. The required size of the stack can greatly vary depending on the OS used, the CPU architecture, the type of application, etc. Refer to the documentation of the OS for more details about tasks and stack size calculation.	From the minimal to the maximal stack size supported by the OS used. The default value can be set for instance to **512**.

Table - Audio Internal Tasks' Configuration Constants

When configuring audio tasks, you should pay attention to their priority. Indeed, audio tasks runs against the internal core task responsible for control transfers and asynchronous transfers. In general, it is recommended to set the core task's priority higher than the audio tasks priority. It will ensure that control transfers carrying standard and class-specific requests will be processed in a timely fashion. Also, audio tasks rely on asynchronous implementation of isochronous transfers. Thus, prioritizing the core task guarantees that isochronous transfers completion is processed fast enough. Even if streams are open, control transfers are occasional. They won't really disturb the stream processing.

The audio class has two internal tasks: playback and record. There is no recommendation about if playback task should have higher priority than record task or the opposite. You just need to ensure that these internal tasks have a higher priority than any of your application tasks. Audio data are considered as real-time data. Thus, you should prioritize the audio streams processing over other functionalities of your application whenever possible.

Audio Topology Configuration

The audio class provides several structures that can be used to build an audio function topology. These structures relate to units, terminals and streams. They will be declared and initialized in `usbd_audio_dev_cfg.h` and `usbd_audio_dev_cfg.c` files. Table - User Configurable Structures for Creating Audio Function Topology in the *Audio Topology Configuration* page presents all configurable structures and the associated function that will use the structure. Functions are described in Class Instance Configuration section.

Structure	Description	Associated Function
`USBD_AUDIO_IT_CFG`	Configures an Input terminal.	`USBD_Audio_IT_Add()`
`USBD_AUDIO_OT_CFG`	Configures an Output terminal.	`USBD_Audio_OT_Add()`
`USBD_AUDIO_FU_CFG`	Configures a Feature Unit.	`USBD_Audio_FU_Add()`
`USBD_AUDIO_MU_CFG`	Configures a Mixer Unit.	`USBD_Audio_MU_Add()`
`USBD_AUDIO_SU_CFG`	Configures a Selector Unit.	`USBD_Audio_SU_Add()`
`USBD_AUDIO_AS_ALT_CFG`	Configures an operational AudioStreaming interface.	`USBD_Audio_AS_IF_Cfg()`
`USBD_AUDIO_AS_IF_CFG`	Gathers information about all alternate settings configuration for a given AudioStreaming interface.	`USBD_Audio_AS_IF_Add()` `USBD_Audio_AS_IF_Cfg()`
`USBD_AUDIO_STREAM_CFG`	Configures stream in terms of buffers and built-in stream correction.	`USBD_Audio_AS_IF_Cfg()`

Table - User Configurable Structures for Creating Audio Function Topology

The use of these structures makes the audio function topology highly configurable. It allows to describe **any type** of audio topology.

Several tables will follow describing all fields of all units, terminals and streams structures. All units, terminals structures and some stream structures' fields follow the associated descriptor content defined in audio 1.0 specification. That's why some tables will indicate which audio 1.0 specification section to refer to for more details when it is relevant. Matching the descriptor content defined in the audio 1.0 specification allows to easily understand the audio function topology configuration.

The file `usbd_audio_dev_cfg.c` located in

```
\Micrium\Software\uC-USB-Device-V4\Cfg\Template\
```

It shows a typical example of terminal, unit and stream structures configuration:

- Two Inputs terminals
- Two Ouput terminals
- Two Feature units
- Two AudioStreaming interfaces

Figure - usbd_audio_dec_cfg.c - Typical Topologies Example in the *Audio Topology Configuration* page gives a visual representation of the possible topologies that can be built with the 6 terminals and units.

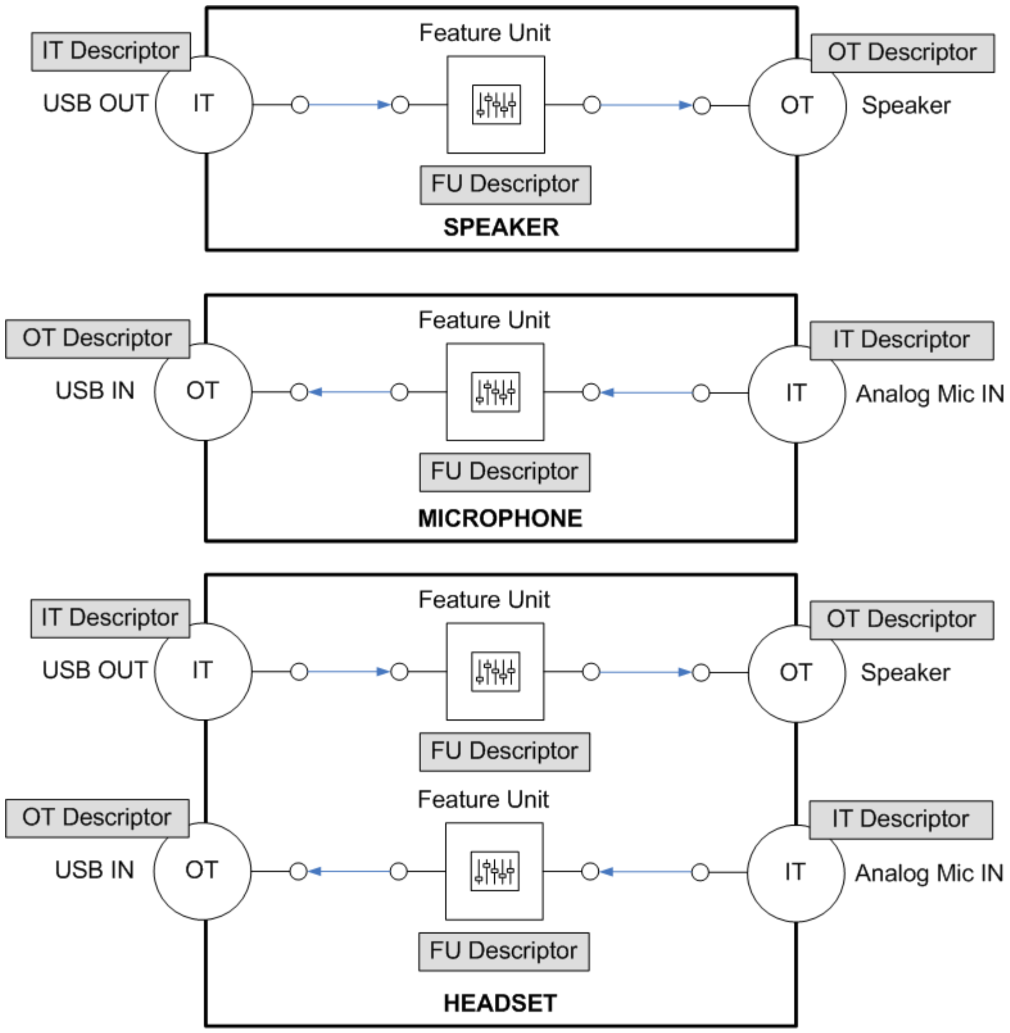


Figure - usbd_audio_dec_cfg.c - Typical Topologies Example

Terminals

All terminals must have a unique ID within a given audio function. The terminals ID assignment is handled by the audio class using the functions `USBD_Audio_IT_Assoc` and `USBD_Audio_OT_Assoc` .

Input Terminal

Table - USBD_AUDIO_IT_CFG Structure Fields Description in the *Audio Topology Configuration* page presents the Input terminal structure. Refer to audio 1.0 specification, section "4.3.2.1 Input Terminal Descriptor" for more details about certain fields.

Field	Description	Example of value	Available Predefined Value

`TerminalType`	Terminal type.	`USBD_AUDIO_TERMINAL_TYPE_MIC`	There are many terminal type defined by Audio 1.0 Terminal Types specification. Thus, there are many predefined values available in `usbd_audio.h`. Some of them typical for IT are:
			`USBD_AUDIO_TERMINAL_TYPE_USB_STREAMING`
			`USBD_AUDIO_TERMINAL_TYPE_IT_UNDEFINED`
			`USBD_AUDIO_TERMINAL_TYPE_MIC`
			`USBD_AUDIO_TERMINAL_TYPE_DESKTOP_MIC`
			`USBD_AUDIO_TERMINAL_TYPE_OMNI_DIR_MIC`
			`USBD_AUDIO_TERMINAL_TYPE_PERSONAL_MIC`
			`USBD_AUDIO_TERMINAL_TYPE_MIC_ARRAY`
			`USBD_AUDIO_TERMINAL_TYPE_PROC_MIC_ARRAY`
			Refer to `usbd_audio.h` for the complete list.

`LogChNbr`	Number of logical output channels in the terminal output.	`USBD_AUDIO_MONO`	`USBD_AUDIO_MONO`
			`USBD_AUDIO_STEREO`
			`USBD_AUDIO_5_1`
			`USBD_AUDIO_7_1`

`LogChCfg`	Spatial location of logical channel.	`USBD_AUDIO_SPATIAL_LOCATION_LEFT_FRONT`	A `OR` combination of:
			`USBD_AUDIO_SPATIAL_LOCATION_LEFT_FRONT`
			`USBD_AUDIO_SPATIAL_LOCATION_RIGHT_FRONT`
			`USBD_AUDIO_SPATIAL_LOCATION_CENTER_FRONT`
			`USBD_AUDIO_SPATIAL_LOCATION_LFE`
			`USBD_AUDIO_SPATIAL_LOCATION_LEFT_SURROUND`
			`USBD_AUDIO_SPATIAL_LOCATION_RIGHT_SURROUND`
			
			`USBD_AUDIO_SPATIAL_LOCATION_LEFT_CENTER`
			`USBD_AUDIO_SPATIAL_LOCATION_RIGHT_CENTER`
			`USBD_AUDIO_SPATIAL_LOCATION_SURROUND`
			`USBD_AUDIO_SPATIAL_LOCATION_SIDE_LEFT`
			`USBD_AUDIO_SPATIAL_LOCATION_SIDE_RIGHT`
			`USBD_AUDIO_SPATIAL_LOCATION_TOP`

`CopyProtEn`	Enables or disables Copy Protection.	`DEF_DISABLED`	`DEF_DISABLED` `DEF_ENABLED`

`CopyProtLevel`	Copy Protection Level.	`USBD_AUDIO_CPL_NONE`	`USBD_AUDIO_CPL_NONE`
			`USBD_AUDIO_CPL0`
			`USBD_AUDIO_CPL1`
			`USBD_AUDIO_CPL2`

`StrPtr`	Pointer to a string describing the Input Terminal.	"IT Microphone"	-

Table - USBD_AUDIO_IT_CFG Structure Fields Description

Output Terminal

Table - USBD_AUDIO_OT_CFG Structure Fields Description in the *Audio Topology Configuration* page presents the Output terminal structure. Refer to audio 1.0 specification, section "4.3.2.2 Output Terminal Descriptor" for more details about certain fields.

Field	Description	Example of value	Available Predefined Value

`TerminalType`	Terminal type.	`USBD_AUDIO_TERMINAL_TYPE_USB_STREAMING`	There are many terminal type defined by Audio 1.0 Terminal Types specification.
			
			Thus, there are many predefined values available in `usbd_audio.h`. Some of them typical for OT are:
			
			`USBD_AUDIO_TERMINAL_TYPE_USB_STREAMING`
			`USBD_AUDIO_TERMINAL_TYPE_SPEAKER`
			`USBD_AUDIO_TERMINAL_TYPE_HEADPHONES`
			`USBD_AUDIO_TERMINAL_TYPE_HEAD_MOUNTED`
			`USBD_AUDIO_TERMINAL_TYPE_DESKTOP_SPEAKER`
			`USBD_AUDIO_TERMINAL_TYPE_ROOM_SPEAKER`
			`USBD_AUDIO_TERMINAL_TYPE_COMM_SPEAKER`
			`USBD_AUDIO_TERMINAL_TYPE_LOW_FREQ_SPEAKER`
			
			Refer to `usbd_audio.h` for the complete list.

`SourceID`	Unit or Terminal ID to which Terminal is connected to.	7	-
`CopyProtEn`	Enables or disables Copy Protection.	`DEF_DISABLED`	`DEF_DISABLED` `DEF_ENABLED`
`StrPtr`	Pointer to a string describing the Output Terminal.	"OT Speaker"	-

Table - USBD_AUDIO_OT_CFG Structure Fields Description

Units

All units must have a unique ID within a given audio function. The units ID assignment is handled by the audio class using the functions `USBD_Audio_FU_Assoc` , USBD_Audio_MU_Assoc() and USBD_Audio_SU_Assoc.

Feature Unit

Table - USBD_AUDIO_FU_CFG Structure Fields Description in the *Audio Topology Configuration* page presents the Feature Unit structure. Refer to audio 1.0 specification, section "4.3.2.5 Feature Unit Descriptor" for more details about certain fields.

Field	Description	Example of value	Available Predefined Value

`LogChNbr`	Number of logical channels.	`USBD_AUDIO_STEREO`	`USBD_AUDIO_MONO`
			`USBD_AUDIO_STEREO`
			`USBD_AUDIO_5_1`
			`USBD_AUDIO_7_1`

`LogChCtrlPtr`	Pointer to Feature Unit Controls table	`&FU_LogChCtrlTbl[0u]`	-
`StrPtr`	Pointer to a string describing the Feature Unit.	"FU Microphone"	-

Table - USBD_AUDIO_FU_CFG Structure Fields Description

`LogChCtrlPtr` points to a table of 16-bit unsigned integers. These integers are used as bitmaps to describe which Feature Unit controls are supported by a certain logical channel. Refer to Table - Units and Terminals Description, Controls and Requests in the *Audio Class Overview* page for the complete list of Feature Unit controls. An audio stream encodes several logical channels forming a cluster. For instance, in a stereo stream, left and right channel are two logical channels. Each Feature Unit can apply a certain control to a specific logical channel or to all channels at once. The *master* channel is used to designate all channels. The code snippet below shows an example of Feature Unit controls table. The table index represents the logical channel number.

```
CPU_INT16U  FU_LogChCtrlTbl[] = {
   (USBD_AUDIO_FU_CTRL_MUTE | USBD_AUDIO_FU_CTRL_VOL),          (1)
    USBD_AUDIO_FU_CTRL_NONE,                                    (2)
    USBD_AUDIO_FU_CTRL_NONE                                     (3)
};
```

Listing - Example of Feature Unit Controls Configuration

(1) Controls supported by the master channel. In this example, mute and volume controls are supported. If the host sends a class-specific request to mute, muting will be applied on left and right channels at the same time. All the possible #define for Feature Unit controls are available in `usbd_audio.h`.

(2) Controls supported by the logical channel #1, i.e. left channel. Here, `USBD_AUDIO_FU_CTRL_NONE` indicates that no controls are supported for the left channel. For example, the host cannot change the volume on the left channel only. It has to change it via the master channel.

(3) Controls supported by the logical channel #2, i.e. right channel. As for the left channel, no controls are supported.

Mixer Unit

Table - USBD_AUDIO_MU_CFG Structure Fields Description in the *Audio Topology Configuration* page presents the Mixer Unit structure. Refer to audio 1.0 specification, section "4.3.2.3 Mixer Unit Descriptor" for more details about certain fields.

Field	Description	Example of value	Available Predefined Value
`NbrInPins`	Number of Input Pins.	3	-

`LogInChNbr`	Number of logical input channels.	`(3 * USBD_AUDIO_STEREO)`	`USBD_AUDIO_MONO`
			`USBD_AUDIO_STEREO`
			`USBD_AUDIO_5_1`
			`USBD_AUDIO_7_1`

`LogOutChNbr`	Number of logical output channels.	`USBD_AUDIO_STEREO`	`USBD_AUDIO_MONO`
			`USBD_AUDIO_STEREO`
			`USBD_AUDIO_5_1`
			`USBD_AUDIO_7_1`

`LogOutChCfg`	Spatial location of logical output channels.	`(USBD_AUDIO_SPATIAL_LOCATION_LEFT_FRONT`
		`|`
		`USBD_AUDIO_SPATIAL_LOCATION_RIGHT_FRONT)`
			A `OR` combination of:
			`USBD_AUDIO_SPATIAL_LOCATION_LEFT_FRONT`
			`USBD_AUDIO_SPATIAL_LOCATION_RIGHT_FRONT`
			`USBD_AUDIO_SPATIAL_LOCATION_CENTER_FRONT`
			`USBD_AUDIO_SPATIAL_LOCATION_LFE`
			`USBD_AUDIO_SPATIAL_LOCATION_LEFT_SURROUND`
			`USBD_AUDIO_SPATIAL_LOCATION_RIGHT_SURROUND`
			
			`USBD_AUDIO_SPATIAL_LOCATION_LEFT_CENTER`
			`USBD_AUDIO_SPATIAL_LOCATION_RIGHT_CENTER`
			`USBD_AUDIO_SPATIAL_LOCATION_SURROUND`
			`USBD_AUDIO_SPATIAL_LOCATION_SIDE_LEFT`
			`USBD_AUDIO_SPATIAL_LOCATION_SIDE_RIGHT`
			`USBD_AUDIO_SPATIAL_LOCATION_TOP`

`StrPtr`	Pointer to a string describing the Mixer Unit.	"Mixer unit 11"	-

Table - USBD_AUDIO_MU_CFG Structure Fields Description

The total number of logical input channels (`LogInChNbr`) is equal to the addition of all logical input channels that composes each input pin. For instance, if a Mixer Unit has 3 inputs pins with the following logical input channels characteristics:

- Input pin #1: stereo
- Input pin #2: mono
- Input pin #3: stereo

Thus the total number would be 5 in this example.

A Mixer Unit can have programmable and non-programmable mixing controls. If you need to set some programmable mixing controls, you need to use the function `USBD_Audio_MU_MixingCtrlSet` during the audio function initialization.

Selector Unit

Table - USBD_AUDIO_SU_CFG Structure Fields Description in the *Audio Topology Configuration* page presents the Selector Unit structure. Refer to audio 1.0 specification, section "4.3.2.4 Selector Unit Descriptor" for more details about certain fields.

Field	Description	Example of value
`NbrInPins`	Number of Input Pins.	2
`StrPtr`	Pointer to a string describing the Selector Unit.	"Selector unit 12"

Table - USBD_AUDIO_SU_CFG Structure Fields Description

Streams

General Stream Configuration

Table - USBD_AUDIO_STREAM_CFG Structure Fields Description in the *Audio Topology Configuration* page presents the general stream configuration structure.

Field	Description	Example of value	Available Predefined Value
`MaxBufNbr`	Maximum number of buffers allocated for the given stream.	40	`USBD_AUDIO_STREAM_NBR_BUF_6` `USBD_AUDIO_STREAM_NBR_BUF_12` `USBD_AUDIO_STREAM_NBR_BUF_18` `USBD_AUDIO_STREAM_NBR_BUF_24` `USBD_AUDIO_STREAM_NBR_BUF_30` `USBD_AUDIO_STREAM_NBR_BUF_36` `USBD_AUDIO_STREAM_NBR_BUF_42`
`CorrPeriodMs`	Period at which the built-in stream correction must be possibly applied. Expressed in milliseconds. For this field and the two followings, refer to section Stream Correction for more details about the built-in correction for playback and record streams.	2	-

Table - USBD_AUDIO_STREAM_CFG Structure Fields Description

AudioStreaming Interface

Table - USBD_AUDIO_AS_ALT_CFG Structure Fields Description in the *Audio Topology Configuration* page presents the AudioStreaming interface configuration structure. Each AudioStreaming interface has one unique associated isochronous endpoint. Hence, there is a one-to-one relation between an AudioStreaming interface and its associated endpoint.

Field	Description	Example of value	Available Predefined Value
AudioStreaming Interface Information			
`Dly`	The Delay holds a value that is a measure for the delay that is introduced in the audio data stream due to internal processing of the signal within the audio function. The delay unit is expressed in number of frames (i.e. in ms). Refer to 'USB Device Class Definition for Audio Devices, Release 1.0, March 18, 1998', section 4.5.2 for more details about class-specific AudioStreaming descriptor.	1	-

`FmtTag`	Audio data format supported by this interface.	`USBD_AUDIO_DATA_FMT_TYPE_I_PCM`	Only formats supported by Type I are possible:
			`USBD_AUDIO_DATA_FMT_TYPE_I_PCM`
			`USBD_AUDIO_DATA_FMT_TYPE_I_PCM8`
			`USBD_AUDIO_DATA_FMT_TYPE_I_IEEE_FLOAT`
			`USBD_AUDIO_DATA_FMT_TYPE_I_ALAW`
			`USBD_AUDIO_DATA_FMT_TYPE_I_MULAW`

Type I Format Information. Refer to 'USB Device Class Definition for Audio Data Formats, Release 1.0, March 18, 1998', section '2.2.5 Type I Format Type Descriptor' for more details about the following fields.			

`NbrCh`	Number of physical channels in the audio data stream.	`USBD_AUDIO_STEREO`	`USBD_AUDIO_MONO`
			`USBD_AUDIO_STEREO`
			`USBD_AUDIO_5_1`
			`USBD_AUDIO_7_1`

`SubframeSize`	Number of bytes occupied by one audio subframe.	`USBD_AUDIO_FMT_TYPE_I_SUBFRAME_SIZE_2`	`USBD_AUDIO_FMT_TYPE_I_SUBFRAME_SIZE_1`
			`USBD_AUDIO_FMT_TYPE_I_SUBFRAME_SIZE_2`
			`USBD_AUDIO_FMT_TYPE_I_SUBFRAME_SIZE_3`
			`USBD_AUDIO_FMT_TYPE_I_SUBFRAME_SIZE_4`

`BitRes`	Effectively used bits in an audio subframe.	`USBD_AUDIO_FMT_TYPE_I_BIT_RESOLUTION_16`	`USBD_AUDIO_FMT_TYPE_I_BIT_RESOLUTION_8`
			`USBD_AUDIO_FMT_TYPE_I_BIT_RESOLUTION_16`
			`USBD_AUDIO_FMT_TYPE_I_BIT_RESOLUTION_24`
			`USBD_AUDIO_FMT_TYPE_I_BIT_RESOLUTION_32`

`NbrSamplingFreq`	Number of discrete sampling frequencies. A value of 0 indicates a continuous sampling frequency range. A value between 1 and 255 indicates a certain number of discrete sampling frequencies supported by the isochronous data endpoint.	2	`USBD_AUDIO_FMT_TYPE_I_SAM_FREQ_CONTINUOUS` or number of discrete sampling frequencies.
`LowerSamplingFreq`	Lower bound in Hz of the continuous sampling frequency range. Valid only for continuous sampling frequency.	0	`USBD_AUDIO_FMT_TYPE_I_SAMFREQ_8KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_11KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_16KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_22KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_32KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_44_1KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_48KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_88_2KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_96KHZ`
`UpperSamplingFreq`	Upper bound in Hz of the continuous sampling frequency range. Valid only for continuous sampling frequency.	0	`USBD_AUDIO_FMT_TYPE_I_SAMFREQ_8KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_11KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_16KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_22KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_32KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_44_1KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_48KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_88_2KHZ` `USBD_AUDIO_FMT_TYPE_I_SAMFREQ_96KHZ`
`SamplingFreqTblPtr`	Pointer to table of discrete sampling frequencies. Valid only for discrete sampling frequencies.	`&AS_SamFreqTbl[0u]`	-
AudioStreaming Endpoint Information			
Standard Endpoint Information			
`EP_DirIn`	Flag indicating if the direction is IN.	`DEF_YES`	`DEF_NO` `DEF_YES`
`EP_SynchType`	Synchronization type supported by Isochronous endpoint.	`USBD_EP_TYPE_SYNC_ASYNC`	`USBD_EP_TYPE_SYNC_NONE` `USBD_EP_TYPE_SYNC_ASYNC` `USBD_EP_TYPE_SYNC_ADAPTIVE` `USBD_EP_TYPE_SYNC_SYNC`
Class-Specific Endpoint Information. Refer to audio 1.0 specification, section 4.6.1.2 for more details about these fields.			

`EP_Attrib`	Class specific controls supported by isochronous endpoint.	`USBD_AUDIO_AS_EP_CTRL_SAMPLING_FREQ`	A `OR` combination of:
			`USBD_AUDIO_AS_EP_CTRL_SAMPLING_FREQ`
			`USBD_AUDIO_AS_EP_CTRL_PITCH`
			`USBD_AUDIO_AS_EP_CTRL_MAX_PKT_ONLY`
			or simply `USBD_AUDIO_AS_EP_CTRL_NONE` if no controls are supported.

`EP_LockDlyUnits`	Indicates the units used for the `LockDly` field.This field and the following works together. These fields relate to 'bLockDelayUnits' and 'wLockDelay' fields of Class-Specific AS Isochronous Audio Data Endpoint Descriptor. 'bLockDelayUnits' and 'wLockDelay' indicate to the Host how long it takes for the clock recovery circuitry of this endpoint to lock and reliably produce or consume the audio data stream. Only applicable for synchronous and adaptive endpoints.	`USBD_AUDIO_AS_EP_LOCK_DLY_UND`	`USBD_AUDIO_AS_EP_LOCK_DLY_UND`
			`USBD_AUDIO_AS_EP_LOCK_DLY_MS`
			`USBD_AUDIO_AS_EP_LOCK_DLY_PCM`

`EP_LockDly`	Indicates the time it takes this endpoint to reliably lock its internal clock recovery circuitry. Units used depend on the value of the `LockDlyUnits` field.	0	-
Synch Endpoint Information			

`EP_SynchRefresh`	Refresh rate of the feedback endpoint (also called Synch endpoint). Feedback endpoint refresh rate represents the exponent of power of 2 ms. The value must be between 1 (2 ms) and 9 (512 ms). This field is valid only if the endpoint is an asynchronous OUT endpoint or an adaptive IN endpoint,	0	-

Table - USBD_AUDIO_AS_ALT_CFG Structure Fields Description

The table pointed by `SamplingFreqTblPtr` can be declared as shown below:

```
CPU_INT32U  AS_SamFreqTbl[] = {
    USBD_AUDIO_FMT_TYPE_I_SAMFREQ_44_1KHZ,
    USBD_AUDIO_FMT_TYPE_I_SAMFREQ_48KHZ
};
```

Listing - Example of Table Declaration of Discrete Number of Supported Sampling Frequencies

Table - USBD_AUDIO_AS_IF_CFG Structure Fields Description in the *Audio Topology Configuration* page presents the structure used to gather information about all alternate settings configuration for a given AudioStreaming interface.

Field	Description	Example of value
`AS_CfgPtrTbl`	Table of pointers to USBD_AUDIO_AS_ALT_CFG structure. Refer to Table - USBD_AUDIO_AS_ALT_CFG Structure Fields Description in the *Audio Topology Configuration* page for more details about USBD_AUDIO_AS_ALT_CFG structure.	`&USBD_AS_IF1_Alt_SpeakerCfgTbl[0u],`
`AS_CfgAltSettingNbr`	Nbr of alternate settings for given AS IF	3

Table - USBD_AUDIO_AS_IF_CFG Structure Fields Description

Table pointed by `AS_CfgPtrTbl` can be declared as shown below:

```
USBD_AUDIO_AS_ALT_CFG  *USBD_AS_IF1_Alt_SpeakerCfgTbl[] = {     (1)
   &USBD_AS_IF1_Alt1_SpeakerCfg,
   &USBD_AS_IF1_Alt2_SpeakerCfg,
   &USBD_AS_IF1_Alt3_SpeakerCfg,
};
```

Listing - Example of Table Declaration of AudioStreaming Alternate Setting Interfaces

(1) The table indicates that the AudioStreaming interface describing a speaker has three possible alternate settings. The host PC will choose one of them when opening the speaker stream based on the resources allocated by the PC for thus AudioStreaming interface.

Audio Class Instance Configuration

Before starting the communication phase, your application needs to initialize and configure the class to suit your needs. Table - Audio Class Initialization API Summary in the *Audio Class Instance Configuration* page summarizes the initialization functions provided by the audio class. For more details about the functions parameters, refer to the Audio API.

Function Name	Operation
`USBD_Audio_Init()`	Initializes audio class internal structures, variables and the OS layer.
`USBD_Audio_Add()`	Creates a new instance of audio class.
`USBD_Audio_CfgAdd()`	Adds an existing audio instance to the specified device configuration.
`USBD_Audio_IT_Add()`	Adds an Input Terminal to the specified audio instance.
`USBD_Audio_OT_Add()`	Adds an Output Terminal to the specified audio instance.
`USBD_Audio_FU_Add()`	Adds a Feature Unit to the specified audio instance.
`USBD_Audio_MU_Add()`	Adds a Mixer Unit to the specified audio instance.
`USBD_Audio_SU_Add()`	Adds a Selector Unit to the specified audio instance.
`USBD_Audio_IT_Assoc`	Associates an Output Terminal to the Input Terminal.
`USBD_Audio_OT_Assoc`	Specifies the entity ID (terminal or unit) connected to the specified Output Terminal and associates an Input Terminal to it.
`USBD_Audio_FU_Assoc`	Specifies the entity ID (terminal or unit) connected to the specified Feature Unit.
`USBD_Audio_MU_Assoc`	Specifies the entities ID (terminal, unit) connected to the specified Mixer Unit.
`USBD_Audio_SU_Assoc`	Specifies the entities ID (terminal, unit) connected to the specified Selector Unit.
`USBD_Audio_MU_MixingCtrlSet`	Sets the mixing controls.
`USBD_Audio_AS_IF_Cfg( )`	Configures the stream characteristics.
`USBD_Audio_AS_IF_Add()`	Add an AudioStreaming interface to the specified audio instance.

Table - Audio Class Initialization API Summary

You need to call these functions in the order shown below to successfully initialize the audio class:

1. Call `USBD_Audio_Init()`
   This is the first function you should call and you should do it only once even if you use multiple class instances. This function initializes all internal structures and variables that the class needs.

2. Call `USBD_Audio_Add()`
   This function allocates an audio class instance. The audio instance represents an Audio Interface Collection (AIC). This function allows you to specify the Audio Peripheral Driver API.

3. Call `USBD_Audio_CfgAdd()`
   Once the audio class instance has been created, you must add it to a specific configuration.

4. Call `USBD_Audio_IT_Add()`
   This function adds an Input Terminal with its configuration to a specific AIC. An audio function will always have at least one Input Terminal. Hence, this function should be called at least once.

5. Call `USBD_Audio_OT_Add()`
   This function adds an Output Terminal with its configuration to a specific AIC. An audio function will always have at least one Output Terminal. Hence, this function should be called at least once.

6. Call `USBD_Audio_FU_Add()`
   This function adds a Feature Unit with its configuration to a specific AIC. Most of the time, an audio function will have at least one Feature Unit to control the stream (for example mute, volume).

7. Call `USBD_Audio_MU_Add()`
   This function adds a Mixer Unit with its configuration to a specific AIC. An audio function may have a Mixer Unit. In general, basics audio devices don't need a Mixer Unit (for instance microphone, speaker, headset). Hence, calling this function is optional.

8. Call `USBD_Audio_SU_Add()`
   This function adds a Selector Unit with its configuration to a specific AIC. An audio function may have a Selector Unit. In general, basics audio devices don't need a Selector Unit (for instance microphone, speaker, headset). Hence, calling this function is optional.

9. Call `USBD_Audio_IT_Assoc`
   This function associates an Output to the Input Terminal. The function is required if

your audio device contains a bi-directional terminal. This terminal type describes an Input and an Output Terminal for voice communication that are closely related. If your device does not have a bi-directional terminal, calling this function is optional.

10. Call `USBD_Audio_OT_Assoc()`
    This function Specifies the entity ID (terminal or unit) connected to the specified Output Terminal and associates an Input Terminal to it.

11. Call `USBD_Audio_FU_Assoc()`
    This function specifies the terminal or unit connected to the Feature Unit.

12. Call `USBD_Audio_MU_Assoc()`
    This function specifies the terminals and/or units connected to the Mixer Unit. If your audio function does not have a Mixer Unit, calling this function is optional.

13. Call `USBD_Audio_SU_Assoc()`
    This function specifies the terminals and/or units connected to the Selector Unit. If your audio function does not have a Selector Unit, calling this function is optional.

14. Call `USBD_Audio_MU_MixingCtrlSet`
    This function configures the programmable mixing controls.

15. Call `USBD_Audio_AS_IF_Cfg()`
    This function configures a given stream according to some specified characteristics.

16. Call `USBD_Audio_AS_IF_Add()`
    This function adds an AudioStreaming interface with its configuration to a specific AIC. You can specify a name for the AudioStreaming interface.

Listing - Audio Class Initialization Example in the *Audio Class Instance Configuration* page illustrates the use of the previous functions for initializing an audio class. Note that the error handling has been omitted for clarity.

The listing does not show an example of usage of the functions `USBD_Audio_MU_Assoc` , `USBD_Audio_SU_Assoc()` and `USBD_Audio_MU_MixingCtrlSet()` to avoid overloading the code snippet. Refer to the associated function page documentation for an example.

```
#define  APP_CFG_USBD_AUDIO_TASKS_Q_LEN                    20u
#define  APP_CFG_USBD_AUDIO_NBR_ENTITY                      6u

CPU_INT08U  Speaker_IT_USB_OUT_ID;                              (1)
CPU_INT08U  Speaker_OT_ID;
CPU_INT08U  Speaker_FU_ID;


static void  App_USBD_Audio_Conn   (CPU_INT08U            dev_nbr,
                                    CPU_INT08U            cfg_nbr,
                                    CPU_INT08U            terminal_id,
                                    USBD_AUDIO_AS_HANDLE  as_handle);

static void  App_USBD_Audio_Disconn(CPU_INT08U            dev_nbr,
                                    CPU_INT08U            cfg_nbr,
                                    CPU_INT08U            terminal_id,
                                    USBD_AUDIO_AS_HANDLE  as_handle);



const  USBD_AUDIO_EVENT_FNCTS  App_USBD_Audio_EventFncts = {
    App_USBD_Audio_Conn,
    App_USBD_Audio_Disconn
};


CPU_BOOLEAN  App_USBD_Audio_Init (CPU_INT08U  dev_nbr,
                                  CPU_INT08U  cfg_hs,
                                  CPU_INT08U  cfg_fs)
{
    USBD_ERR                 err;
    CPU_INT08U               audio_nbr;
    USBD_AUDIO_AS_IF_HANDLE  speaker_playback_as_if_handle;

                                                                /* Init Audio class.
*/
    USBD_Audio_Init(APP_CFG_USBD_AUDIO_TASKS_Q_LEN,             (2)
                   &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
                                                                /* Create an audio class instance.
*/
    audio_nbr = USBD_Audio_Add(APP_CFG_USBD_AUDIO_NBR_ENTITY,   (3)
                               &USBD_Audio_DrvCommonAPI_Simulation,
                               &App_USBD_Audio_EventFncts,
                               &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
    if (cfg_hs != USBD_CFG_NBR_NONE) {
                                                                /* --------------- ADD HS CONFIGURATION
--------------- */
        USBD_Audio_CfgAdd(audio_nbr,                            (4)
                          dev_nbr,
                          cfg_hs,
                         &err);
        if (err != USBD_ERR_NONE) {
            /* $$$$ Handle the error. */
        }
    }

    if (cfg_fs != USBD_CFG_NBR_NONE) {
                                                                /* --------------- ADD FS CONFIGURATION
--------------- */
        USBD_Audio_CfgAdd(audio_nbr,                            (5)
                          dev_nbr,
                         cfg_fs,
                        &err);
        if (err != USBD_ERR_NONE) {
            /* $$$$ Handle the error. */
        }
    }
                                                            /* ----------- BUILD AUDIO FUNCTION
TOPOLOGY ---------- */
                                                            /* Add terminals and units.
*/
    Speaker_IT_USB_OUT_ID = USBD_Audio_IT_Add(audio_nbr,        (6)
                                             &USBD_IT_USB_OUT_Cfg,
                                             &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
    Speaker_OT_ID = USBD_Audio_OT_Add(audio_nbr,
                                     &USBD_OT_SPEAKER_Cfg,
                                      DEF_NULL,
                                     &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }

    Speaker_FU_ID = USBD_Audio_FU_Add(audio_nbr,
                                     &USBD_FU_SPEAKER_Cfg,
                                     &USBD_Audio_DrvFU_API_Simulation,
                                     &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
                                                            /* Bind terminals and units.
*/
    USBD_Audio_IT_Assoc(audio_nbr,                              (7)
                        Speaker_IT_USB_OUT_ID,
                        USBD_AUDIO_TERMINAL_NO_ASSOCIATION,
                       &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
    USBD_Audio_OT_Assoc(audio_nbr,
                        Speaker_OT_ID,
                        Speaker_FU_ID,
                        USBD_AUDIO_TERMINAL_NO_ASSOCIATION,
                       &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
    USBD_Audio_FU_Assoc(audio_nbr,
                        Speaker_FU_ID,
                        Speaker_IT_USB_OUT_ID,
                       &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }

                                                            /* ----------- CONFIGURE AUDIO STREAMING
IF ----------- */
                                                            (8)
   speaker_playback_as_if_handle =  USBD_Audio_AS_IF_Cfg(&USBD_SpeakerStreamCfg,
                                                        &USBD_AS_IF1_SpeakerCfg,
                                                        &USBD_Audio_DrvAS_API_Simulation,
                                                        &App_USBD_Audio_MemSegInfo,
                                                         Speaker_IT_USB_OUT_ID,
                                                         DEF_NULL,
                                                        &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
    if (cfg_hs != USBD_CFG_NBR_NONE) {
                                                                /* -------------- ADD AUDIO STREAMING IF
-------------- */
        USBD_Audio_AS_IF_Add(audio_nbr,                         (9)
                              cfg_hs,
                              speaker_playback_as_if_handle,
                             &USBD_AS_IF1_SpeakerCfg,
                             "Speaker AudioStreaming IF",
                             &err);
        if (err != USBD_ERR_NONE) {
            /* $$$$ Handle the error. */
        }
    }
    if (cfg_fs != USBD_CFG_NBR_NONE) {
                                                                /* -------------- ADD AUDIO STREAMING IF
-------------- */
        USBD_Audio_AS_IF_Add(audio_nbr,                         (10)
                              cfg_fs,
                              speaker_playback_as_if_handle,
                             &USBD_AS_IF1_SpeakerCfg,
                             "Speaker AudioStreaming IF",
                             &err);
        if (err != USBD_ERR_NONE) {
            /* $$$$ Handle the error. */
        }
    }
    return (DEF_OK);
}
```

Listing - Audio Class Initialization Example

(1) These global variables will contain the terminal and unit IDs assigned by the audio class. These global variables can then be accessed by the Audio Peripheral Driver when processing class requests and streaming data.

(2) Initialize audio class internal structures, variables and OS layer. The queue size for the playback and record tasks is passed to the function. In this example, the constant `APP_CFG_USBD_AUDIO_TASKS_Q_LEN` indicates that each task queue can contain up to 20 messages.

(3) Create a new audio class instance. `USBD_Audio_DrvCommonAPI_Simulation` represents the Audio Peripheral Driver API. The API structure will be used by the Audio Processing module to execute a certain action associated to a class request. Refer to Audio Peripheral Driver Guide for more details about the Audio Peripheral Driver API. The structure `App_USBD_Audio_EventFncts` contains class event callbacks called by the class during specific moments. The callback `App_USBD_Audio_Conn()` is called when the host selects a device configuration. This callback is called for each AudioStreaming interface. You may retrieve some audio statistics from this callback (cf. page Audio Statistics). The

callback `App_USBD_Audio_Disconn()` is called once when the host selects a new device configuration, resets the device configuration or the USB device stack is stopped internally by the embedded application.

(4) Check if the high-speed configuration is active and proceed to add the audio instance previously created to this configuration.

(5) Check if the full-speed configuration is active and proceed to add the audio instance to this configuration.

(6) Build the audio function topology by adding all the required terminals and units. In this example, a speaker topology is built by adding an Input Terminal of type USB OUT, an Output Terminal of type Speaker and a Feature Unit to control the mute and volume controls of the speaker stream. This topology corresponds to the one shown in Figure - usbd_audio_dec_cfg.c - Typical Topologies Example in the *Audio Topology Configuration* page. The audio class assigned a unique ID to each terminal and unit. Each ID can be stored in a global variable accessible by the Audio Peripheral Driver for class requests and stream data processing. The associated terminal or unit configuration structure is passed to the function `USBD_Audio_XX_Add()`. Information contained in these structures will be stored internally in the audio class. Refer to Audio Topology Configuration page for more details about terminal and unit configuration structure. `USBD_IT_USB_OUT_Cfg`, `USBD_OT_SPEAKER_Cfg` and `USBD_FU_SPEAKER_Cfg` are declared in the file `usbd_audio_dev_cfg.c` located in \ *Micrium\Software\uC-USB-Device-V4\Cfg\Template\*. Output Terminal, Feature, Mixer and Selector units Add() functions can receive an associated API provided by the Audio Peripheral Driver. In this example, the Output Terminal has no API associated, `DEF_NULL` is passed. Whereas the Feature Unit has the API `USBD_Audio_DrvFU_API_Simulation`.

(7) Build the connection between terminals and units using the ID assigned by the audio class. The terminals and units connection is based on the input pin(s). An Input Terminal has no input pin. Thus no entity source ID is passed as argument of `USBD_Audio_IT_Assoc()`. In this example, a speaker is built. The speaker does not use a bi-directional terminal (that is an Input and Output Terminals working together). So the constant `USBD_AUDIO_TERMINAL_NO_ASSOCIATION` is passed as argument to `USBD_Audio_IT_Assoc()` and `USBD_Audio_OT_Assoc()` . The call to the function `USBD_Audio_IT_Assoc()` is not mandatory if there is no bi-directional terminal within the audio function.

(8) Configure the AudioStreaming interface with all the information passed as argument. In the example, the AudioStreaming interface is a speaker stream. The general speaker stream configuration structure, `USBD_SpeakerStreamCfg` , and the AudioStreaming interface configuration structure, `USBD_AS_IF1_SpeakerCfg,` are passed. Refer to section Streams for more details about these structures. Internally, the audio class will perform some checks and store any relevant information for the stream communication. The function will allocate buffers for the given stream taken into account the alignment requirement indicated by `USBD_AUDIO_CFG_BUF_ALIGN_OCTETS` . Buffers can be allocated from a general purpose heap or from the a specific memory segment. In the example, buffers will be allocated from the heap because a `DEF_NULL` pointer is passed. Refer to the page `USBD_Audio_AS_IF_Cfg` for an example of buffers allocated from a memory segment. The terminal ID associated to this stream is also passed to the function. The 6th argument is a `DEF_NULL` pointer, that is you don't provide an application playback stream correction callback. The audio class has a built-in stream correction enabled by `USBD_AUDIO_CFG_PLAYBACK_CORR_EN` or `USBD_AUDIO_CFG_RECORD_CORR_EN` configuration constants. If `USBD_AUDIO_CFG_PLAYBACK_CORR_EN` is set to `DEF_ENABLED` and the stream is a playback stream, you have the possibility to provide a callback that will implement your own playback stream correction in case of overrun and underrun situations. Listing - Example of Playback Correction Callback Provided by the Application in the *Audio Class Stream Data Flow* page gives an example of an application playback stream correction callback declaration. Refer to Stream Correction for more details about the built-in stream correction.

At the end, the function returns an handle identifying the stream.

(9) Add to the high-speed configuration an AudioStreaming interface. In the example, the stream handle returned by `USBD_Audio_AS_IF_Cfg()` and the AudioStreaming interface structure, `USBD_AS_IF1_SpeakerCfg` , are passed to the function.

(10) Add to the full-speed configuration an AudioStreaming interface. The different parameters passed to the function are the same as the one described in (8).

Audio Statistics

During the development of your audio function, you may be interested in knowing what is happening during stream communication. The audio class offers a few statistics per AudioStreaming interface. The configuration constant `USBD_AUDIO_CFG_STAT_EN` allows you to activate the audio stream statistics. You need to set it to `DEF_ENABLED`.

You will have to use the structure `USBD_AUDIO_STAT` in your audio application to get statistics. This structure collects long-term statistics for a given AudioStreaming interface, that is each time the corresponding stream is opened and used by the host. The statistics are not reset when the stream is closed. Listing - Getting Audio Statistics in the Application in the *Audio Statistics* page shows how to retrieve audio statistics from your application.

```
#if (USBD_AUDIO_CFG_STAT_EN == DEF_ENABLED)                     (1)
USBD_AUDIO_STAT  *App_SpeakerStatPtr;                           (2)
USBD_AUDIO_STAT  *App_MicStatPtr;
#endif
                                                                (3)
static  void  App_USBD_Audio_Conn (CPU_INT08U           dev_nbr,
                                   CPU_INT08U           cfg_nbr,
                                   CPU_INT08U           terminal_id,
                                   USBD_AUDIO_AS_HANDLE as_handle);

const  USBD_AUDIO_EVENT_FNCTS App_USBD_Audio_EventFncts = {
    App_USBD_Audio_Conn,
    App_USBD_Audio_Disconn
};

CPU_BOOLEAN  App_USBD_Audio_Init (CPU_INT08U  dev_nbr,
                                  CPU_INT08U  cfg_hs,
                                  CPU_INT08U  cfg_fs)
{
    ...

    audio_nbr = USBD_Audio_Add(APP_CFG_USBD_AUDIO_NBR_ENTITY,
                              &USBD_Audio_DrvCommonAPI_Simulation,
                              &App_USBD_Audio_EventFncts,       (4)
                              &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
    ...
    return (DEF_OK);
}
                                                                (5)
static void  App_USBD_Audio_Conn(CPU_INT08U            dev_nbr,
                                 CPU_INT08U            cfg_nbr,
                                 CPU_INT08U            terminal_id,
                                 USBD_AUDIO_AS_HANDLE  as_handle)
{
    (void)&dev_nbr;
    (void)&cfg_nbr;
#if (USBD_AUDIO_CFG_STAT_EN == DEF_ENABLED)
    if (terminal_id == Mic_OT_USB_IN_ID) {                      (6)
        App_MicStatPtr = USBD_Audio_AS_IF_StatGet(as_handle);
    } else if (terminal_id == Speaker_IT_USB_OUT_ID) {
        App_SpeakerStatPtr = USBD_Audio_AS_IF_StatGet(as_handle);
    }
#else
    (void)&terminal_id;
    (void)&p_as_if_arg;
#endif
}
```

Listing - Getting Audio Statistics in the Application

(1) Your debug code for audio statistics could be surrounded by some preprocessor directives testing `USBD_AUDIO_CFG_STAT_EN`.

(2) Declare a pointer to an `USBD_AUDIO_STAT` structure. You can have one pointer per stream you want to follow. In the example, the pointers `App_SpeakerStatPtr` and

`App_MicStatPtr` allows respectively to monitor the speaker and record streams.

(3) Declare a connection event function that will be called by the audio class when the device configuration is selected by the host. In this example, the function named `App_USBD_Audio_Conn()` will allow you to retrieve references to the speaker and record stream statistics structures. This function will initialize a function pointer from the audio event structure `USBD_AUDIO_EVENT_FNCTS`.

(4) When creating an audio class instance with `USBD_Audio_Add()`, the third argument will be a reference to the structure containing the connection event function.

(5) The audio class will call `App_USBD_Audio_Conn()` for each AudioStreaming interface.

(6) Call the function `USBD_Audio_AS_IF_StatGet()`to get statistics about the microphone in the example. The audio class will return a reference to the `USBD_AUDIO_STAT` structure assigned to the microphone stream. This reference is kept by the pointer `App_MicStatPtr` . You may have to check the terminal ID if you have several audio streams statistics to retrieve. For each stream, call again `USBD_Audio_AS_IF_StatGet()` . The audio statistics structure can be consulted during debug operations in a watch window for instance.

Table - USBD_AUDIO_STAT Structure Fields Description in the *Audio Statistics* page gives more details about the fields of `USBD_AUDIO_STAT` structure. The fields are basically counters that are incremented to follow a certain statistic. Counters are placed strategically inside the audio class to monitor the stream communication.The column "Description" will refer to the stream data flow. Refer to Audio Class Stream Data Flow as a complement to fully understand counters.

Field	Description	Function
Related to Playback		
`AudioProc_Playback_NbrIsocRxSubmitSuccess`	Total number of isochronous OUT transfers successfully submitted to the USB device driver. The sum of `AudioProc_Playback_NbrIsocRxSubmitPlaybackTask` with `AudioProc_Playback_NbrIsocRxSubmitCoreTask` should be equal to this counter when a stream is closed.	`USBD_Audio_PlaybackPrime()` `USBD_Audio_PlaybackUsbBufSubmit()`
`AudioProc_Playback_NbrIsocRxSubmitErr`	Number of isochronous OUT transfers submitted to the USB device driver with an error.	`USBD_Audio_PlaybackPrime()` `USBD_Audio_PlaybackUsbBufSubmit()`
`AudioProc_Playback_NbrIsocRxSubmitPlaybackTask`	Number of isochronous OUT transfers successfully submitted by the Playback task.	`USBD_Audio_PlaybackUsbBufSubmit()`
`AudioProc_Playback_NbrIsocRxSubmitCoreTask`	Number of isochronous OUT transfers successfully submitted by the Core task.	`USBD_Audio_PlaybackIsocCmpl()` `USBD_Audio_PlaybackPrime()`
`AudioProc_Playback_NbrIsocRxCmpl`	Number of isochronous OUT transfers completed with or without error. That is `USBD_Audio_PlaybackIsocCmpl()` has been called by the Core task.	`USBD_Audio_ Playback IsocCmpl()`
`AudioProc_Playback_NbrIsocRxCmplErrOther`	Number of isochronous OUT transfers completed with an error different from `USBD_ERR_EP_ABORT`. That is `USBD_Audio_ Playback IsocCmpl()` has been called by the Core task.	`USBD_Audio_ Playback IsocCmpl()`
`AudioProc_Playback_NbrIsocRxCmplErrAbort`	Number of isochronous OUT transfers completed with the error code `USBD_ERR_EP_ABORT` . When a stream closes, a few isochronous transfers may be pending in the USB device driver, the Core task aborts all pending transfers by calling `USBD_Audio_ Playback IsocCmpl()` with the error code `USBD_ERR_EP_ABORT` . This error code is a *normal* error.	`USBD_Audio_ Playback IsocCmpl()`
`AudioProc_Playback_NbrIsocRxBufNotAvail`	Number of times no buffer available for Playback and Core tasks while preparing a new isochronous transfer.	`USBD_Audio_PlaybackUsbBufSubmit()`
`AudioProc_Playback_NbrReqPostPlaybackTask`	Number of requests submitted to the Playback task. A request is a stream handle sent when opening the playback stream and each time an audio transfer is finished. At the stream closing, this counter should be equal to `AudioProc_Playback_NbrReqPendPlaybackTask`.	`USBD_Audio_PlaybackTxCmpl()`
`AudioProc_Playback_NbrReqPendPlaybackTask`	Number of requests retrieved by the Playback task. Each time the Playback task wakes up, this counter is incremented.	`USBD_Audio_PlaybackTaskHandler()`

`AudioProc_Playback_NbrIsocRxOngoingCnt`	Current number of isochronous OUT transfers in progress. That is transfers have been submitted to the USB device driver but are not yet finished. A transfer is being processed or transfers are waiting to be processed by the USB device controller.	`USBD_Audio_AS_IF_Start()` `USBD_Audio_PlaybackIsocCmpl()` `USBD_Audio_PlaybackPrime()` `USBD_Audio_PlaybackUsbBufSubmit()`
Related to Playback Feedback: all these counters are available only if `USBD_AUDIO_CFG_PLAYBACK_FEEDBACK_EN` is set to `DEF_ENABLED` .		
`AudioProc_Playback_SynchNbrBufGet`	Number of feedback buffers obtained each time a new feedback value must be sent to the host. There is one and unique feedback buffer per stream. If a new feedback value is to be sent and the single buffer is already in use, this feedback value is lost. The counter `AudioProc_Playback_SynchNbrBufNotAvail` indicates the feedback values lost.	`USBD_Audio_PlaybackSynchBufGet()`
`AudioProc_Playback_SynchNbrBufFree`	Number of feedback buffers made available again. The unique feedback buffer is made available each time an isochronous IN transfer completes or in case of error when submitting an isochronous transfer with the function `USBD_IsocTxAsync()`.	`USBD_Audio_PlaybackSynchBufFree()`
`AudioProc_Playback_SynchNbrBufNotAvail`	Number of times the unique feedback buffer is not available because already in use. In that case, the feedback value is lost.	`USBD_Audio_PlaybackCorrSynch()` `USBD_Audio_PlaybackCorrSynchInit()`
`AudioProc_Playback_SynchNbrSafeZone`	Number of normal situations without feedback correction.	`USBD_Audio_PlaybackCorrSynch()`
`AudioProc_Playback_SynchNbrOverrun`	Number of overrun situations requiring feedback correction.	`USBD_Audio_PlaybackCorrSynch()`
`AudioProc_Playback_SynchNbrLightOverrun`	Number of light overrun situations. Refer to section Playback Feedback Correction for more details about a light overrun.	`USBD_Audio_PlaybackCorrSynch()`
`AudioProc_Playback_SynchNbrHeavyOverrun`	Number of heavy overrun situations. Refer to section Playback Feedback Correction for more details about a heavy overrun.	`USBD_Audio_PlaybackCorrSynch()`
`AudioProc_Playback_SynchNbrUnderrun`	Number of underrun situations requiring feedback correction.	`USBD_Audio_PlaybackCorrSynch()`
`AudioProc_Playback_SynchNbrLightUnderrun`	Number of light underrun situations. Refer to section Playback Feedback Correction for more details about a light underrun.	`USBD_Audio_PlaybackCorrSynch()`
`AudioProc_Playback_SynchNbrHeavyUnderrun`	Number of heavy underrun situations. Refer to section Playback Feedback Correction for more details about a heavy underrun.	`USBD_Audio_PlaybackCorrSynch()`

`AudioProc_Playback_SynchNbrRefreshPeriodReached`	Number of times the refresh period has been reached, The audio device reports a feedback value every bRefresh period. This bRefresh period is defined in the feedback Endpoint descriptor retrieved by the host during the enumeration. The audio class evaluates the feedback correction each time a playback buffer is received from host. When the number of frames elapsed matches the bRefresh period, a feedback value is sent. Refer to section Playback Feedback Correction for more details.	`USBD_Audio_PlaybackCorrSynch()`
`AudioProc_Playback_SynchNbrIsocTxSubmitted`	Number of isochronous IN transfers successfully submitted to the USB device driver.	`USBD_Audio_PlaybackCorrSynch()` `USBD_Audio_PlaybackCorrSynchInit()`
`AudioProc_Playback_SynchNbrIsocTxCmpl`	Number of isochronous IN transfers completed with or without an error. That is `USBD_Audio_IsocPlaybackSynchCmpl ()` has been called by the Core task.	`USBD_Audio_PlaybackIsocSynchCmpl()`
Related to Record		
`AudioProc_Record_NbrIsocTxSubmitSuccess`	Total number of isochronous IN transfers successfully submitted to the USB device driver. The sum of `AudioProc_Record_NbrIsocTxSubmitRecordTask` with `AudioProc_Record_NbrIsocTxSubmitCoreTask` should be equal to this counter when a stream is closed.	`USBD_Audio_RecordPrime()` `USBD_Audio_RecordUsbBufSubmit()`
`AudioProc_Record_NbrIsocTxSubmitErr`	Number of isochronous IN transfers submitted to the USB device driver with an error.	`USBD_Audio_RecordPrime()` `USBD_Audio_RecordUsbBufSubmit()`
`AudioProc_Record_NbrIsocTxSubmitRecordTask`	Number of isochronous IN transfers successfully submitted by the Record task.	`USBD_Audio_RecordTaskHandler()`
`AudioProc_Record_NbrIsocTxSubmitCoreTask`	Number of isochronous IN transfers successfully submitted by the Core task.	`USBD_Audio_RecordIsocCmpl()`
`AudioProc_Record_NbrIsocTxCmpl`	Number of isochronous IN transfers completed with or without an error. That is `USBD_Audio_RecordIsocCmpl ()` has been called by the Core task.	`USBD_Audio_RecordIsocCmpl()`
`AudioProc_Record_NbrIsocTxCmplErrOther`	Number of isochronous IN transfers completed with an error different from `USBD_ERR_EP_ABORT` . That is `USBD_Audio_RecordIsocCmpl()` has been called by the Core task.	`USBD_Audio_RecordIsocCmpl()`
`AudioProc_Record_NbrIsocTxCmplErrAbort`	Number of isochronous IN transfers completed with the error code `USBD_ERR_EP_ABORT` . When a stream closes, a few isochronous transfers may be pending in the USB device driver, the Core task aborts all pending transfers by calling `USBD_Audio_RecordIsocCmpl()` with the error code `USBD_ERR_EP_ABORT`. This error code is a *normal* error.	`USBD_Audio_RecordIsocCmpl()`
`AudioProc_Record_NbrIsocTxBufNotAvail`	Number of times no buffer available for Record and Core tasks while preparing a new isochronous transfer.	`USBD_Audio_RecordPrime()` `USBD_Audio_RecordUsbBufSubmit()`

`AudioProc_Record_NbrReqPostRecordTask`	Number of requests submitted to the Record task. A request is a stream handle sent each time a record buffer ready to be sent to the host is signaled to the Record task by the Audio Peripheral Driver. When the stream is closed, this counter should be equal to `AudioProc_Record_NbrReqPendRecordTask`.	`USBD_Audio_RecordRxCmpl()`
`AudioProc_Record_NbrReqPendRecordTask`	Number of requests retrieved by the Record task. Each time the Record task wakes up, this counter is incremented.	`USBD_Audio_RecordTaskHandler()`
Related to Playback and Record		
`AudioProc_RingBufQ_NbrProducerStartIxCatchUp`	Number of times the index `ProducerStart` has caught up the index `ConsumerEnd` and/or `ProducerEnd`.	`USBD_Audio_AS_IF_RingBufQProducerSt`
`AudioProc_RingBufQ_NbrProducerEndIxCatchUp`	Number of times the index `ProducerEnd` has caught up the index `ProducerStart` and/or `ConsumerStart` .	`USBD_Audio_AS_IF_RingBufQProducerEn`
`AudioProc_RingBufQ_NbrConsumerStartIxCatchUp`	Number of times the index `ConsumerStart` has caught up the index `ProducerEnd` and/or `ConsumerEnd`.	`USBD_Audio_AS_IF_RingBufQConsumerSt`
`AudioProc_RingBufQ_NbrConsumerEndIxCatchUp`	Number of times the index `ConsumerEnd` has caught up the index `ConsumerStart` and/or `ProducerStart`.	`USBD_Audio_AS_IF_RingBufQConsumerEn`
`AudioProc_RingBufQ_NbrProducerStartIxWrapAround`	Number of wrap-around for the index `ProducerStart` of the ring buffer queue.	`USBD_Audio_AS_IF_RingBufQIxUpdate()`
`AudioProc_RingBufQ_NbrProducerEndIxWrapAround`	Number of wrap-around for the index `ProducerEnd` of the ring buffer queue.	`USBD_Audio_AS_IF_RingBufQIxUpdate()`
`AudioProc_RingBufQ_NbrConsumerStartIxWrapAround`	Number of wrap-around for the index Consumer `Start` of the ring buffer queue.	`USBD_Audio_AS_IF_RingBufQIxUpdate()`
`AudioProc_RingBufQ_NbrConsumerEndIxWrapAround`	Number of wrap-around for the index `ConsumerEnd` of the ring buffer queue.	`USBD_Audio_AS_IF_RingBufQIxUpdate()`
`AudioProc_RingBufQ_NbrBufDescInUse`	Number of buffer descriptors in use by playback or record streams. Buffer descriptors are used internally by the audio class, in particular to support multi-streaming. It allows the Playback or Record task to manage buffers from different AudioStreaming interfaces.	`USBD_Audio_AS_IF_RingBufQConsumerEn` `USBD_Audio_AS_IF_RingBufQProducerSt` `USBD_Audio_AS_IF_Start()`
`AudioProc_RingBufQ_NbrErr`	Number of times there was an error getting a buffer from the ring buffer queue.	`USBD_Audio_PlaybackBufSubmit()` `USBD_Audio_PlaybackIsocCmpl()` `USBD_Audio_PlaybackPrime()` `USBD_Audio_PlaybackUsbBufSubmit()` `USBD_Audio_RecordBufGet()` `USBD_Audio_RecordIsocCmpl()` `USBD_Audio_RecordPrime()` `USBD_Audio_RecordTaskHandler()` `USBD_Audio_RecordUsbBufSubmit()`

`AudioProc_NbrStreamOpen`	Number of times the stream has been open by the host. This counter is incremented when the host sends a SET_INTERFACE request to the device with a non-null alternate setting.	`USBD_Audio_AS_IF_Start()`
`AudioProc_NbrStreamClosed`	Number of times the stream has been closed. This counter is incremented when the host sends a SET_INTERFACE request to the device with a null alternate setting and when an internal error within the audio class occurs requiring to mark the stream as closed. When a stream is closed and no error occurs internally, this counter should be equal to `AudioProc_NbrStreamOpen`.	`USBD_Audio_AS_IF_Stop()` `USBD_Audio_IsocPlaybackCmpl()`
`AudioProc_CorrNbrUnderrun`	Number of underrun situations requiring built-in playback or record correction.	`USBD_Audio_PlaybackCorrBuiltIn()` `USBD_Audio_RecordCorrBuiltIn()`
`AudioProc_CorrNbrOverrun`	Number of overrun situations requiring built-in playback or record correction.	`USBD_Audio_PlaybackCorrBuiltIn()` `USBD_Audio_RecordCorrBuiltIn()`
`AudioProc_CorrNbrSafeZone`	Number of normal situations without built-in playback or record correction.	`USBD_Audio_PlaybackCorrBuiltIn()` `USBD_Audio_RecordCorrBuiltIn()`
Related to Playback and Record from Audio Peripheral Driver		
`AudioDrv_Playback_DMA_NbrXferCmpl`	Number of playback buffers consumed by the Audio Peripheral Driver. By default, audio statistics are not available in the Audio Peripheral Driver. Since the Audio Peripheral Driver is written by you, you can use the macro `AUDIO_DRV_STAT_INC()` to increment this counter. Refer to Statistics for more details about where to use this macro.	Audio Peripheral Driver
`AudioDrv_Playback_DMA_NbrSilenceBuf`	Number of silence buffers consumed by the Audio Peripheral Driver. If there are no playback buffers ready to play by the codec, the driver should simply send silence buffers. This counter can be incremented with the macro `AUDIO_DRV_STAT_INC()` .	Audio Peripheral Driver
`AudioDrv_Record_DMA_NbrXferCmpl`	Number of record buffers produced by the Audio Peripheral Driver. You can use the macro `AUDIO_DRV_STAT_INC()` to increment this counter.	Audio Peripheral Driver
`AudioDrv_Record_DMA_NbrDummyBuf`	Number of dummy buffers used by the Audio Peripheral Driver because no empty record buffers are available. If there are no record buffers available, the driver may need to falsely consume some record data while waiting for some record buffers to be free. This counter can be incremented with the macro `AUDIO_DRV_STAT_INC()`.	Audio Peripheral Driver

Table - USBD_AUDIO_STAT Structure Fields Description

Audio Class Stream Data Flow

The Audio Processing module manages playback and record streams using two internal tasks:

- Playback task
- Record task

These two tasks are the glue between the µC/USB-Device Core and the Audio Peripheral Driver.

From a host perspective, a stream lifetime will always consist in:

1. Opening a stream,
2. Communicating on this stream,
3. Closing a stream.

Sections below describe in more detailed manner the streams data flow.

Playback Stream

A playback stream carries audio data over an isochronous OUT endpoint. There is a one-to-one relation between an isochronous OUT endpoint, an AudioStreaming interface and a Terminal. Figure - Playback Stream Dataflow in the *Audio Class Stream Data Flow* page presents the audio data flow implemented inside the Audio Processing module. The playback path relies on a ring buffer queue to synchronize the playback task, the core task and the codec ISR.

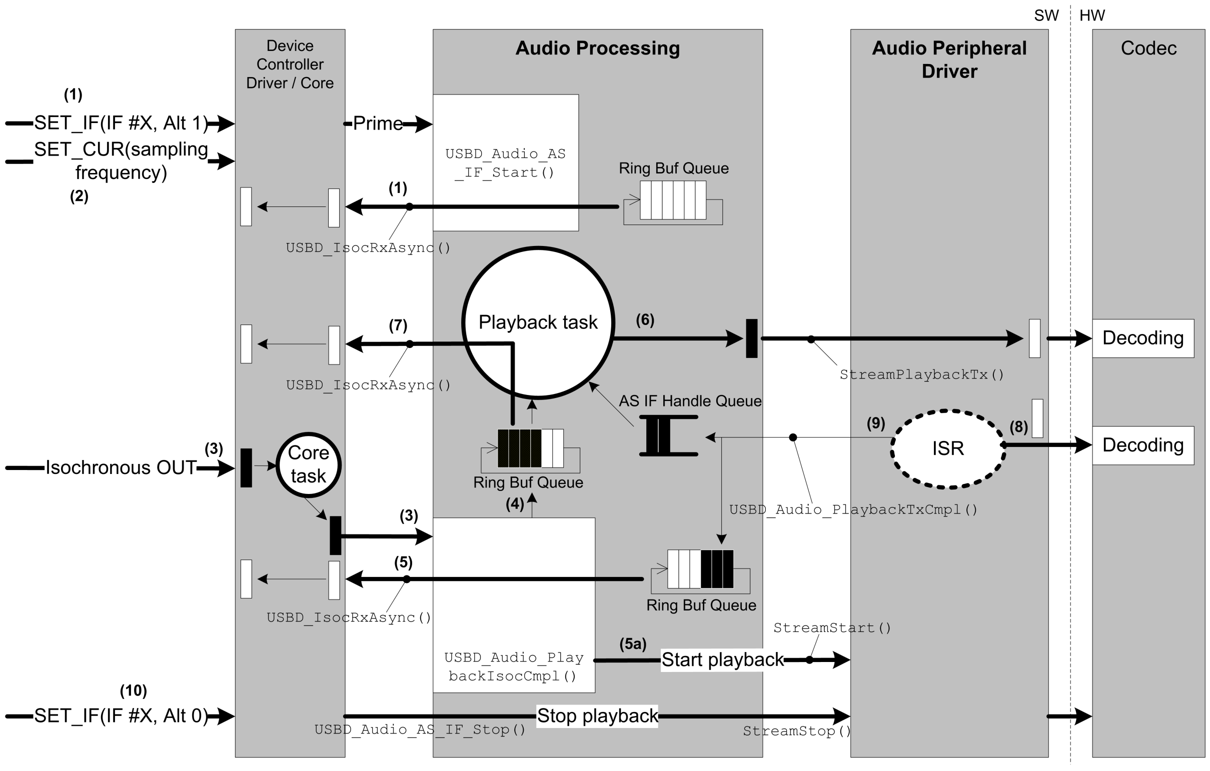


Figure - Playback Stream Dataflow

(1) The host activates the AudioStreaming interface #X by selecting the operational interface (request SET_INTERFACE sent for alternate setting 1). This marks the opening of the playback. The core task will call the function `USBD_Audio_AS_IF_Start()`. The first isochronous OUT transfer is submitted to the USB device driver to **prime** the stream. An empty audio buffer is taken from the ring buffer queue.

(2) The host then sets the sampling frequency for a certain isochronous OUT endpoint by sending a SET_CUR request. The function `USBD_Audio_DrvAS_SamplingFreqManage()` (not indicated in the figure) is called from the core task's context. This function is implemented by the audio peripheral driver and will set a DAC (Digital-to-Analog Converter) clock in the codec.

(3) The USB Device Controller fills the buffer with the isochronous audio data that have been sent by the host. The buffer is retrieved by the core task. As soon as one isochronous transfer is completed, the core task will call the callback `USBD_Audio_PlaybackIsocCmpl()` passed as a parameter of `USBD_IsocRxAsync()` . This

callback notifies the audio class that a buffer with audio samples is ready for the audio codec.

Error Handling

If the isochronous transfer has completed with an error, `USBD_Audio_PlaybackIsocCmpl()` will free the buffer associated to the transfer.

(4) The received buffer is then added to the ring buffer queue.

(5) The core task will submit **all** the buffers it can to the USB device driver to feed the stream communication by calling `USBD_IsocRxAsync()` several times.

(5a) Once a certain number of buffers (pre-buffering threshold) have been accumulated , the playback stream is started on the codec side by calling the function `StreamStart()` . The pre-buffering threshold is always equal to (`MaxBufNbr` / 2). The field `MaxBufNbr` is part of the structure `USBD_AUDIO_STREAM_CFG` . Within `Drv_API_Ptr->PlaybackStart()` , the audio peripheral driver should signal the playback task N times by calling via the function `USBD_Audio_PlaybackTxCmpl()` . N corresponds to the number of buffers it can queue. The driver should at least support the double-buffering and thus queue two buffers.

(6) Signalling the playback task consists in posting an AudioStreaming (AS) interface handle in a queue. The playback task wakes up and processes the handle. It submits a ready buffer taken from the ring buffer queue to the audio peripheral driver by calling the function `StreamPlaybackTx()` . Before being submitted to the audio peripheral driver, the received audio data may go through a correction in case of underrun or overrun situation of ring buffer queue. The playback stream correction is explained in section Playback Stream Correction . The audio peripheral driver should accumulate the ready buffer. After at least two buffers accumulated, the driver should send the first buffer to the codec usually by preparing a DMA transfer.

DMA in Audio Peripheral Driver

The use of DMA transfers is assumed to communicate with the audio codec. It allows to offload the CPU and to optimize performances.

Error Handling

If the ring buffer queue is empty, the playback task waits 1 ms and signals itself to re-submit another ready buffer to the audio peripheral driver. At least one ready buffer should have been inserted in the waiting list during the delay.

(7) In the same way as the core task in `USBD_Audio_PlaybackIsocCmpl()` , the playback task submits all buffers it can to the USB device driver by calling `USBD_IsocRxAsync()` several times.

Error Handling

If the submission with `USBD_IsocRxAsync()` fails by returning an error code, the buffer is freed back to the ring buffer queue.

(8) The buffer contains a chunk (1 ms of audio data) of audio stream. This audio chunk is encoded following a certain format. The audio peripheral driver might have to decode the audio chunk in order to correctly present the audio samples to the codec.

(9) Each time a playback buffer is consumed by the codec, the audio peripheral driver ISR signals to the playback task the end of an audio transfer by calling the function `USBD_Audio_PlaybackTxCmpl()` . This function posts a AS interface handle and free the consumed buffer back to the ring buffer queue.

(10) Afterwards, steps 3 to 9 are repeated over and over again until the host stops the playback by selecting the default AudioStreaming Interface (request SET_INTERFACE sent for alternate setting 0). At this time, the Audio Processing will stop the streaming on the codec side by calling the audio peripheral driver function `StreamStop()` . Basically, any playback DMA transfer is aborted. All the playback buffers attached to pending isochronous transfers will be freed automatically by the core which calls `USBD_Audio_IsocPlaybackCmpl()` for each aborted isochronous transfer.

Refer to page Audio Peripheral Driver Guide for more details about the audio peripheral driver processing.

The playback task supports **multi-streams**. If the audio function uses several USB OUT Terminal types, each USB OUT Terminal is associated to one AudioStreaming interface structure that the playback task manipulates and updates during stream communication.

OS Tick Rate

In case the ring buffer queue is empty when the playback task is submitting a buffer to the audio peripheral driver, a retry mechanism is used to re-submit the buffer 1 ms later. This delay allows other tasks to execute and a new buffer will become available in the ring buffer queue. The function `USBD_Audio_OS_DlyMs()` is used for this delay. Whenever possible, the OS tick rate should have a 1 ms granularity. It will also help for the audio class tasks scheduling as audio class works on a 1 ms frame basis.

Record Stream

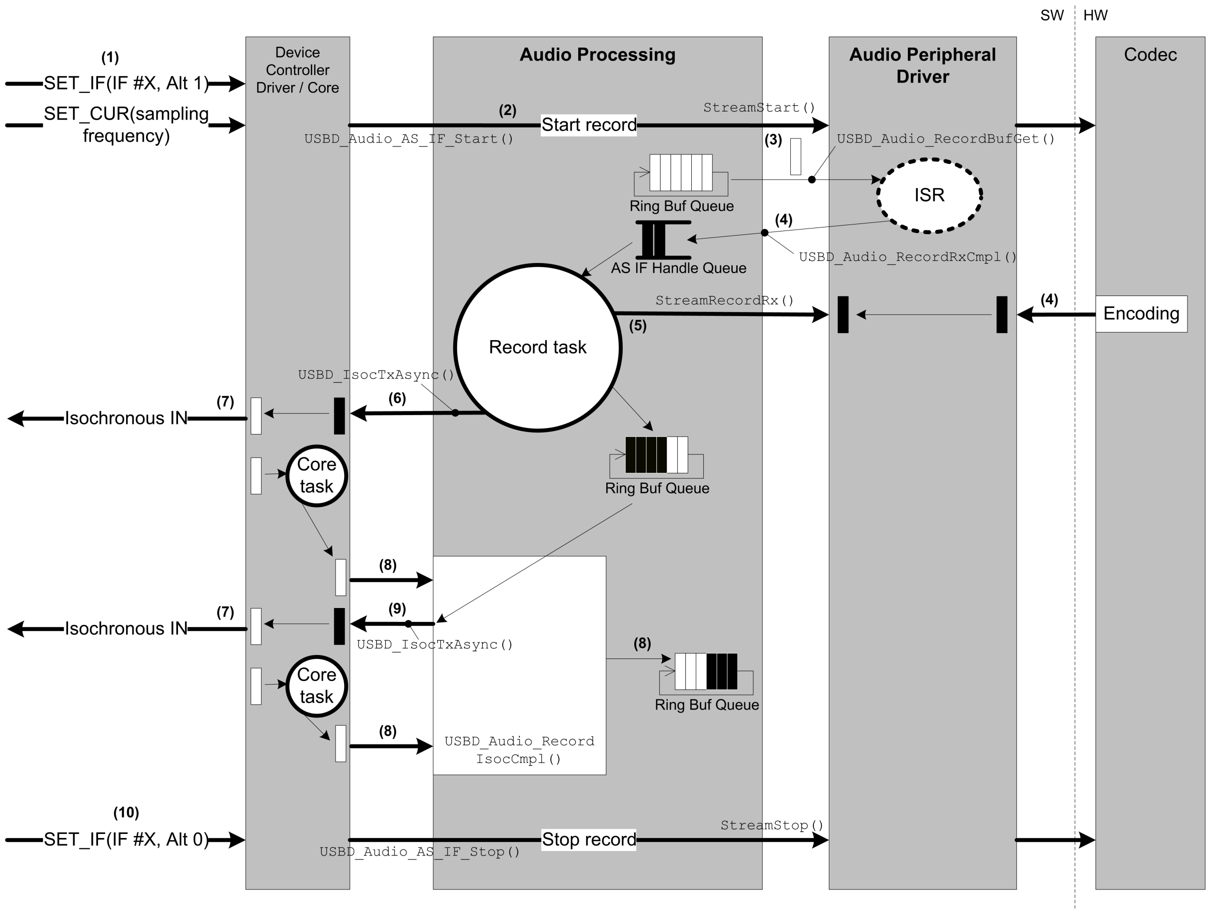


Figure - Record Stream Dataflow

(1) The host activates the AudioStreaming interface #X by selecting the operational interface (request SET_INTERFACE sent for alternate setting 1). The host then sets the sampling frequency for a certain isochronous IN endpoint by sending SET_CUR request. The function `USBD_Audio_DrvAS_SamplingFreqManage` (not indicated in the figure) is called from the core task's context . This function is implemented by the audio peripheral driver and will set an ADC (Analog-to-Digital Converter) clock in the codec.

(2) When processing the SET_CUR(sampling frequency) request, the audio class will also start the record stream on the codec side by calling `StreamStart()` . In this function, a DMA transfer will be prepared to get the first record buffer from the codec. The initial

receive buffer will be obtained by calling `USBD_Audio_RecordBufGet()` . This step is not entirely represented in the figure. The audio class ensures that the record stream is started on the codec side after setting the sampling frequency as a codec needs the correct clock settings before getting record data.

DMA in Audio Peripheral Driver

The use of DMA transfers is assumed to communicate with the audio codec. It allows to offload the CPU and to optimize performances.

(3) Once the first DMA transfer has completed, the audio peripheral driver will obtain the next receive buffer from the ring buffer queue by calling `USBD_Audio_RecordBufGet()` . T his function provides also to the audio peripheral driver the number of bytes to get from the codec.

(4) The buffer will be filled with audio samples given by one or more ADCs (one ADC per logical channel). The buffer will contain 1 ms worth of audio samples. This 1 ms of audio samples should be encoded, either directly by the codec (hardware) or by the audio peripheral driver (software). Most of the time, the codec will provide the chunk of audio stream already encoded. The driver signals the end of an audio transfer to the record task by calling the function `USBD_Audio_RecordRxCmpl()` . The signal represents an AudioStreaming interface handle.

(5) The record task wakes up and retrieves the ready buffer from the audio peripheral driver by calling the audio peripheral driver function `StreamRecordRx()` . The buffer is stored in the ring buffer queue.

(6) To prime the audio stream, the record task waits for a certain number of buffers to be ready. The pre-bufferring threshold is always equal to (`MaxBufNbr` / 2). The field `MaxBufNbr` is part of the structure `USBD_AUDIO_STREAM_CFG` . Once the pre-buffering is done, the record task submits the initial isochronous IN transfer to the USB device driver via `USBD_IsocTxAsync()` . During the stream communication, the record task does not submit other isochronous transfers. Other USB transfers submission is done by the core task.

There is a special situation where the record task can submit a new transfer. When the stream communication loop is broken, that is there are no more ongoing isochronous transfers in the USB device driver, the record task restarts the stream with a new USB transfer.

(7) The USB device driver will send isochronous audio data to the host during a specific frame.

(8) Upon completion of the isochronous IN transfer, the core task will call the callback `USBD_Audio_RecordIsocCmpl()` provided by the Audio Processing as an argument of `USBD_IsocTxAsync()` . This callback will free the buffer by returning it in the ring buffer queue. Before the buffer return int the ring buffer queue, a stream correction may happen for the next record buffer to fill by the codec. The record stream correction is explained in section Record Stream Correction.

Error Handling

If a transfer has completed with an error, the associated buffer is freed by `USBD_Audio_RecordIsocCmpl()`.

(9) The core task submits all the ready buffers it can to the USB device driver by calling `USBD_IsocTxAsync()` several times. The core task is thus responsible to maintain alive the stream communication by repeating the steps 7 and 8.

Error Handling

If the submission with `USBD_IsocTxAsync()` fails by returning an error code, the buffer is freed back to the ring buffer queue ..

(10) Once the audio stream is initiated, the steps 3 to 8 will repeat over and over again until the host stops recording by selecting the default AudioStreaming Interface (request SET_INTERFACE sent for alternate setting 0). At this time, the Audio Processing will stop the streaming on the codec side by calling the audio peripheral driver function `StreamRecordStop()` . Basically, any record DMA transfer will be aborted. All empty buffers being processed and all ready buffers not yet retrieved by the record task are implicitly freed by the ring buffer queue reset. On the USB side, all the record buffers unconsumed will be freed automatically by the core by calling `USBD_Audio_IsocRecordCmpl()` for each aborted isochronous transfers.

Refer to page Audio Peripheral Driver Guide for more details about the audio peripheral driver processing.

The record task supports **multi-streams** . If the audio function uses several USB IN Terminal types, each USB IN Terminal is associated to one AudioStreaming interface structure posted in the record task's queue. Thus the record task can handle buffers from different streams.

The record data path takes care of the **data rate adjustment**. This is required for certain sampling frequencies that do not produce an integer number of audio samples per ms. Partial audio samples are not possible. For those sampling frequencies, the Table - Data Rate Adjustment in the *Audio Class Stream Data Flow* page gives the required adjustment. The data rate adjustment is implemented in the isochronous IN transfer completion callback `USBD_Audio_RecordIsocCmpl()`.

Samples per frame/ms	Typical Packet Size	Adjustment
11.025	11 samples	12 samples every 40 packets (i.e. ms)
22.050	22 samples	23 samples every 20 packets (i.e. ms)
44.1	44 samples	45 samples every 10 packets (i.e. ms)

Table - Data Rate Adjustment

For instance, considering a sampling frequency of 44.1 kHz and a mono microphone, the audio class will send to the host isochronous transfers with a size of 44 samples each frame. In order to have 44 100 samples every second, the audio class will send 45 samples every 10 frames (that is every 10 ms). At one second, the host will have received 100 additional samples added to the 44 000 samples received with the 44-byte isochronous transfers.

Stream Correction

Playback Built-In Stream Correction

The built-in playback stream correction is active only when the constant `USBD_AUDIO_CFG_PLAYBACK_CORR_EN` is set to `DEF_ENABLED`. As explained in section Playback Stream, the stream correction is evaluated before the playback task provides a ready buffer to the audio peripheral driver. The evaluation relies on monitoring the playback ring buffer queue. Two thresholds are defined: a lower limit and an upper limit as shown in Figure - Playback Ring Buffers Queue Monitoring in the *Audio Class Stream Data Flow* page. The figure shows the four indexes used in the ring buffer queue. A buffer difference is computed between the indexes `ProducerEnd` and `ConsumerEnd`. For the playback path, `ProducerEnd` is linked to the USB transfer completion while `ConsumerEnd` is linked to the audio transfer completion. The buffer difference represent a circular distance between two indexes. If the distance is less than the lower limit, you have an underrun situation, that is the USB side does not produce fast enough the audio samples consumed by the codec. Conversely, if the distance is greater than the upper limit, this is an overrun situation, that is the USB side produces faster then the the codec can consume audio data. To keep the codec and USB in sync, a simple algorithm is used to add an audio sample in case of underrun and to remove a sample frame in case of overrun.

The frequency at which the playback stream correction is evaluated is configurable via the field `CorrPeriodMs` of the structure `USBD_AUDIO_STREAM_CFG` .

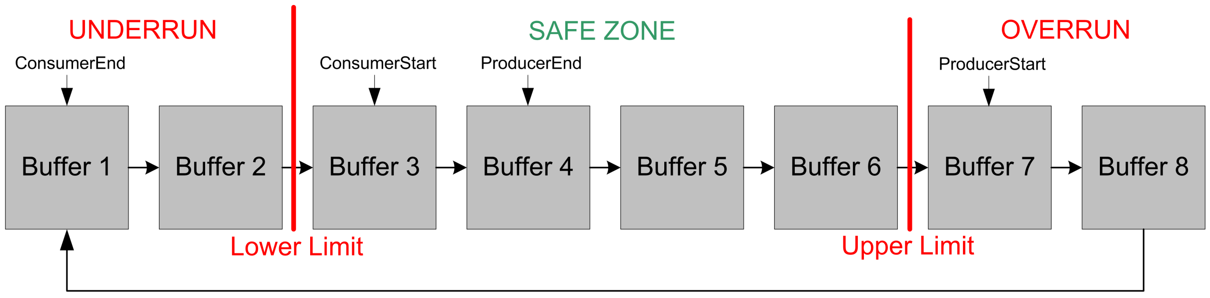


Figure - Playback Ring Buffers Queue Monitoring

Figure - Adding a Sample in Case of Underrun in the *Audio Class Stream Data Flow* page illustrates the algorithm to add an audio sample in case of underrun situation.

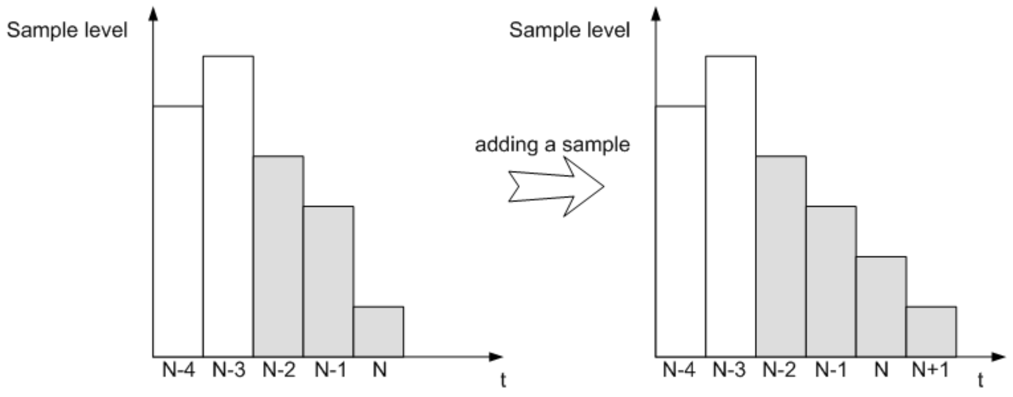


Figure - Adding a Sample in Case of Underrun

(1) Sample N is moved at N+1.

(2) Sample N is rebuilt and equal to the average of N-1 and N+1.

(3) The packet size is increased of one sample.

The frequency at which the playback stream correction is evaluated is configurable via the field `CorrPeriodMs` of the structure `USBD_AUDIO_STREAM_CFG` .

> The stream correction supports signed PCM and unsigned PCM8 format.

> This stream correction is convenient for low-cost audio design. It will give good results as long as the incoming USB audio sampling frequency is very close to the DAC input clock frequency. However, if the difference between the two frequencies is important, this will add audio distortion.

Figure - Removing a Sample in Case of Overrun in the *Audio Class Stream Data Flow* page illustrates the algorithm to remove an audio sample in case of overrun situation.

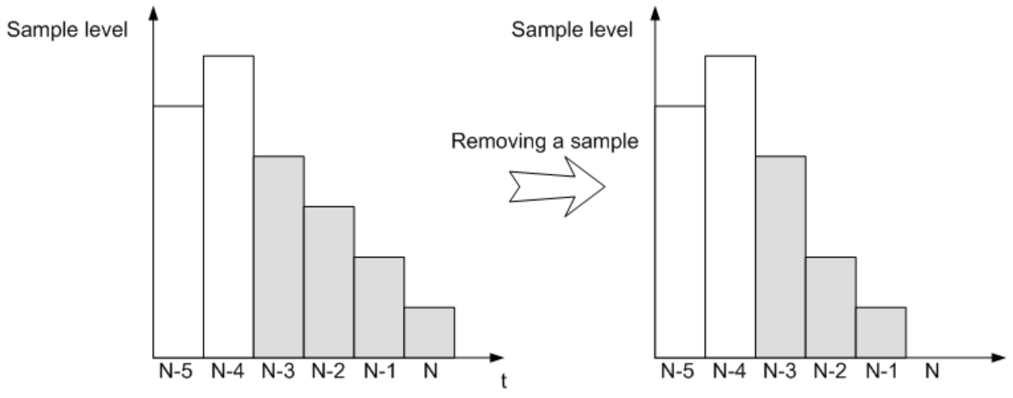


Figure - Removing a Sample in Case of Overrun

(1) Sample N-2 is rebuilt and equal to the average of N, N-1, N-2 and N-3.

(2) Sample N is moved at N-1.

(3) The packet size is reduced of one sample.

The playback stream correction offers the possibility to apply your own correction algorithm. If an underrun or overrun situation is detected, an application callback is called. Listing - Example of Playback Correction Callback Provided by the Application in the *Audio Class Stream Data Flow* page shows an example of playback correction callback prototype and definition provided by the application.

```
(1)
static  CPU_INT16U  App_USBD_Audio_PlaybackCorr(USBD_AUDIO_AS_ALT_CFG  *p_as_alt_cfg,
                                                CPU_BOOLEAN             underrun_flag,
                                                void                   *p_buf,
                                                CPU_INT16U              buf_len_cur,
                                                CPU_INT16U              buf_len_total,
                                                USBD_ERR               *p_err);

CPU_BOOLEAN  App_USBD_Audio_Init (CPU_INT08U  dev_nbr,
                                  CPU_INT08U  cfg_hs,
                                  CPU_INT08U  cfg_fs)
{
    ...
    speaker_playback_as_if_handle = USBD_Audio_AS_IF_Cfg(&USBD_SpeakerStreamCfg,
                                                         &USBD_AS_IF1_SpeakerCfg,
                                                         &USBD_Audio_DrvAS_API_Template,
                                                          DEF_NULL,
                                                          IT2_ID,
                                                          App_USBD_Audio_PlaybackCorr, (2)
                                                         &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
    ...
    return (DEF_OK);
}
/*
*********************************************************************************************************
App_USBD_Audio_PlaybackCorr()
*
* Description : Apply user-defined correction algorithm to the playback stream.
*
* Argument(s) : p_as_alt_cfg       Pointer to AudioStreaming interface configuration structure.
*
*               is_underrun        Flag indicating if an underrun (audio clock faster than USB) or
*                                  overrun (audio clock slower than USB) situation has been detected
*                                  by the Audio class.
*
*               p_buf              Pointer to buffer to which the correction will be applied to.
*
*               buf_len_cur        Current length of the buffer.
*
*               buf_len_total      Total length of the buffer.
*
*               p_err              Pointer to variable that will receive the return error code from
*                                  this function :
*
*                                  USBD_ERR_NONE   Correction successfully applied to buffer.
* Return(s)   : New length of the buffer after correction.
*
* Caller(s)   : USBD_Audio_PlaybackCorr().
*
* Note(s)     : none.
*********************************************************************************************************/
    (3)
static  CPU_INT16U  App_USBD_Audio_PlaybackCorr (USBD_AUDIO_AS_ALT_CFG  *p_as_alt_cfg,
                                                 CPU_BOOLEAN             is_underrun,
                                                 void                   *p_buf,
                                                 CPU_INT16U              buf_len_cur,
                                                 CPU_INT16U              buf_len_total,
                                                 USBD_ERR               *p_err)
{
    (void)&p_as_alt_cfg;
    (void)&is_underrun;
    (void)&p_buf;
    (void)&buf_len_cur;
    (void)&buf_len_total;
   *p_err = USBD_ERR_NONE;

    return (buf_len_cur);
}
```

Listing - Example of Playback Correction Callback Provided by the Application

(1) Prototype of your playback correction callback.

(2) Upon configuration of an AudioStreaming interface with the function `USBD_Audio_AS_IF_Cfg` , the callback function name is passed to the function. You have the possibility to define a different correction callback for each playback AudioStreaming interface composing your audio topology.

(3) Definition of your playback correction callback. Once the playback is open by the host and the built-in playback correction is enabled (`USBD_AUDIO_CFG_PLAYBACK_CORR_EN` set to `DEF_ENABLED`), if an overrun or underrun situation is detected by the Audio Processing module, your callback will be called. You will have access to the structure `USBD_AUDIO_AS_ALT_CFG` associated to this playback stream through the pointer `p_as_alt_cfg`. Among the fields, you may be interested in:

- `TerminalID`: ID of terminal associated to the playback stream.
- `NbrCh`: Number of channels supported by the stream.
- `SubframeSize`: Number of bytes occupied by one audio sample.
- `BitRes`: Effectively used bits in an audio sample.

Beside the AudioStreaming alternate setting configuration structure, you will know the situation type (underrun or overrun via `underrun_flag`), the current buffer length (`buf_len_cur`) and the total buffer length (`buf_len_total`). Then you can apply your own correction algorithm to the buffer referenced by `p_buf`. If some samples are removed or added to the buffer, you will have to return to the Audio Processing module the adjusted buffer length. Note that you can add or remove only one sample at a time. You can also specify an error code if something went wrong while applying your correction.

If p_as_alt_cfg-> BitRes is equal to 8 bits, it means that the audio data is encoded in PCM8 format (for legacy 8-bit wave format). In this format, audio data is represented as unsigned fixed point. You correction algorithm must take into account signed PCM and unsigned PCM8.

Record Built-In Stream Correction

There is also a built-in record stream correction active only when the constant USBD_AUDIO_CFG_RECORD_CORR_EN is set to DEF_ENABLED. As explained in the section Record Stream, when an isochronous IN transfer completes by calling the callback function USBD_Audio_RecordIsocCmpl() , the stream correction is evaluated. The evaluation relies on monitoring the record ring buffer queue. Two thresholds are defined: a lower limit and an upper limit based on the same principle as shown in Figure - Playback Ring Buffers Queue Monitoring in the *Audio Class Stream Data Flow* page. For the record path, ProducerEnd is linked to the audio transfer completion while ConsumerEnd is linked to the USB transfer completion. This is the opposite of the playback. Moreover, the ring buffer queue scheme is common to the playback and record streams. And within the audio class, the definition of overrun and underrun situation is "USB-centric".

Consequently, if the lower limit is reached, you have an overrun situation, that is the USB side consumes a little bit faster than the the codec can produce. Conversely, the upper limit corresponds to an underrun situation, that is the USB side does not consume fast enough the audio samples produced by the codec. As opposed to the playback stream correction, no software algorithm is needed to add or remove an audio sample. The audio class will adjust the audio peripheral hardware by using the number of required record data bytes indicated by USBD_Audio_RecordBufGet() . The correction is done implicitly by the audio peripheral hardware by directly getting the right number of audio samples (-1 sample frame or +1 sample frame) to accommodate the overrun or underrun situation.

The frequency at which the record stream correction is evaluated is configurable via the field CorrPeriodMs of the structure USBD_AUDIO_STREAM_CFG .

Playback Feedback Correction

The feedback correction (refer to section Feedback Endpoint for an overview of feedback) takes place when the configuration constant `USBD_AUDIO_CFG_PLAYBACK_FEEDBACK_EN` is set to `DEF_ENABLED` and the AudioStreaming interface uses an isochronous OUT endpoint with asynchronous synchronization. As explained in section Playback Stream, the stream correction is evaluated in the function `USBD_Audio_PlaybackCorrSynch()` before the playback task provides a ready buffer to the audio peripheral driver.

The feedback value evaluation relies on monitoring the playback ring buffer queue. Based on the same principle as the playback built-in correction, the buffer difference between the indexes `ProducerEnd` and `ConsumerEnd` is computed and gives the reflect at which the USB and codec clocks operate. The feedback monitoring starts only when the playback stream priming is done, that is when the audio class calls the audio peripheral driver function `USBD_Audio_DrvStreamStart` . Once the feedback monitoring has started, the underrun or overrun situation requiring a feedback value to be sent to the host is evaluated using the method shown in Table - Feedback Monitoring in the *Audio Class Stream Data Flow* page.

USB/Codec Clock Difference	USB << Codec		USB < Codec			USB = Codec			USB > Codec		USB >> Codec
Adjustment (in sample)	+1	+1/2	[+1 ; +1/2048]	-	-	-	-	-	[-1/2048 ; -1]	-1/2	-1
buffer difference	-5	-4	-3	-2	-1	0	1	2	3	4	5
Zone	Underrun	Underrun	Underrun	Underrun	Safe	Safe	Safe	Overrun	Overrun	Overrun	Overrun
Threshold	Heavy	Light		No adjustment					Light		Heavy

Table - Feedback Monitoring

The underrun situation occurs when the USB side is slower than the codec. In that case, depending how fast is the codec, the underrun situation could be light or heavy. The processing will adjust the feedback value by telling the host to add up to one sample per frame depending of the underrun degree. Similarly, the overrun situation occurs when the USB side is faster than the codec. In that case, depending how slow is the codec, the overrun situation could be light or heavy. The processing will adjust the feedback value by telling the host to remove up to one sample per frame depending of the overrun degree.

When coming from the safe zone, the light underrun or overrun is corrected with a feedback value taking into account the variation of buffers during a certain number of elapsed frames. This allows to correct smoothly the stream deviation instead of over-shooting the correction. The feedback value adjustment is between a minimum adjustment and a maximum adjustment:

- Underrun situation: +1/2048 sample < adjustment < +1 sample ()
- Overrun situation: -1 sample < adjustment < -1/2048 sample

The first feedback value sent by the device is always the nominal value of samples per frame corresponding to the sampling frequency. For instance, if the sampling frequency is 48.0 kHz, the nominal feedback value send to the host will be 48 samples per frame.

The feedback value update to the host is evaluated every refresh period. The refresh period is configurable via the field `CorrPeriodMs` of the structure `USBD_AUDIO_STREAM_CFG` . When the refresh period is reached, if there is a correction to apply, the feedback value update is sent to the host by calling the function `USBD_IsocTxAsync()` . If there is no correction necessary, the audio class does not prepare an isochronous IN transfer. Thus when the host sends an IN token, a zero-length packet is sent by the device. The host interprets this zero-length packet as "continue to apply the previous valid feedback value". The feedback value is sent in 10.14 format.

Audio 1.0 specification indicates that the feedback refresh period can range from 1 (2 ms) to 9 (512 ms). The refresh period is a power of 2: 2, 4, 8,16, 32, 64, 128, 256, 512. A short bRefresh period will result in a tighter control of the stream data rate. A long bRefresh period may add some latency in the control the stream data rate. Refresh periods such as 256 and 512 should be avoided as they can impact the data rate control. For instance, if the bRefresh is 512 ms and, USB and codec clocks diverge quickly, updates of the feedback value every 512 ms may not be fast enough to re-synchronize USB and codec clocks.

Using the Audio Class Demo Application

Micrium provides a demo application that lets you test and evaluate the class implementation. Source template files are provided.

Note that the demo application provided by Micriµm is only an example and is intended to be used as a starting point to develop your own application.

Configuring Device Application

The audio class provides two demos:

- *Microphone* demo exercises isochronous IN transfers and consequently the record stream and some class-specific requests.
- *Loopback* demo exercises isochronous IN and OUT transfers, that is respectively record and playback streams. Loopback demo can be thought as a headset demo.

The demo application files offering the two audio demos are provided for µC/OS-II and µC/OS-III and should be considered as example that you can modify. The files composing the demo application are:

File	Description	Location
`app_cfg.h`	Contains a few constants to configure its internal tasks.	Not provided in package.
`app_usbd_cfg.h`	Contains constants related to audio class demos.	`\Micrium\Software\uC-USB-Device-V4\App\Device\`
`app_usbd_audio.c`	Allows to initialize audio class. Refer to section Audio Class Instance Configuration for more details.	`\Micrium\Software\uC-USB-Device-V4\App\Device\`
`usbd_audio_drv_simulation.c` `usbd_audio_drv_simulation.h`	Simulates a microphone and a headset used as a loopback.	`\Micrium\Software\uC-USB-Device-V4\App\Device\`

`usbd_audio_drv_simulation_data.c`	Defines audio data waveforms samples used by the microphone demo.	`\Micrium\Software\uC-USB-Device-V4\App\Device\`

The use of these constants usually defined in `app_cfg.h` or `app_usbd_cfg.h` allow you to use one of the audio demos.

Constant	Description	Demo	File
APP_CFG_USBD_AUDIO_DRV_SIMULATION_PRIO	Priority of the task used by the microphone or loopback demo. Since the microphone or loopback task simulates a hardware behavior, the priority of this task should be greater than the priority of the record, playback and core tasks. Furthermore, the microphone or loopback task uses a 1-ms delay in certain circumstances. You should ensure that the tick rate for µC/OS-II or OS-III is set to 1000 ticks per second.	Both	app_cfg.h
APP_CFG_USBD_AUDIO_DRV_SIMULATION_STK_SIZE	Stack size of the tasks used by microphone or loopback demo. A default value can be **512.**	Both	app_cfg.h
APP_CFG_USBD_AUDIO_EN	Enables the audio class demo application. Must be set to DEF_ENABLED.	Both	app_usbd_cfg.h
APP_CFG_USBD_AUDIO_SIMULATION_LOOP_EN	Enables microphone or loopback demo. DEF_DISABLED enables the microphone demo and DEF_ENABLED the loopback demo.	Both	app_usbd_cfg.h
APP_CFG_USBD_AUDIO_DRV_SIMULATION_DATA_WAVEFORM	Selects the sound type, that is the waveform used to generate a certain tone. Possible values are: **USBD_AUDIO_DRV_SIMULATION_DATA_WAVEFORM_SINE** (default) USBD_AUDIO_DRV_SIMULATION_DATA_WAVEFORM_SQUARE USBD_AUDIO_DRV_SIMULATION_DATA_WAVEFORM_SAWTOOTH USBD_AUDIO_DRV_SIMULATION_DATA_WAVEFORM_BEEP_BEEP	Microphone	app_usbd_cfg.h
APP_CFG_USBD_AUDIO_DRV_SIMULATION_DATA_FREQ	Selects frequency of the waveform. Possible values are: **USBD_AUDIO_DRV_SIMULATION_DATA_FREQ_100_HZ** (default) USBD_AUDIO_DRV_SIMULATION_DATA_FREQ_1000_HZ	Microphone	app_usbd_cfg.h
APP_CFG_USBD_AUDIO_TASKS_Q_LEN	Specifies the queue length for playback & record tasks.	Both	app_usbd_cfg.h
APP_CFG_USBD_AUDIO_RECORD_NBR_BUF	Configures the maximum number of record buffers.	Both	app_usbd_cfg.h
APP_CFG_USBD_AUDIO_RECORD_CORR_PERIOD	Configures the record stream built-in correction period in milliseconds.	Both	app_usbd_cfg.h
APP_CFG_USBD_AUDIO_PLAYBACK_NBR_BUF	Configures the maximum number of playback buffers.	Loopback	app_usbd_cfg.h
APP_CFG_USBD_AUDIO_PLAYBACK_CORR_PERIOD	Configures the playback stream built-in correction period in milliseconds.	Loopback	app_usbd_cfg.h
APP_CFG_USBD_AUDIO_NBR_ENTITY	Configures the number of entities composing the audio function.	Both	app_usbd_cfg.h

Table - Device Application Constants Configuration

Stream Correction

It is possible to enable the stream correction for the microphone and loopback demos, that is constants `USBD_AUDIO_CFG_RECORD_CORR_EN`, `USBD_AUDIO_CFG_PLAYBACK_CORR_EN` and/or `USBD_AUDIO_CFG_PLAYBACK_FEEDBACK_EN`. But keep in mind that it does NOT represent a real situation of stream correction usage as both demos simulate the codec behavior using a task and consequently does not represent a real audio timing.

Running the Demo Application

For demos explanation purpose, we will consider the operating system Microsoft Windows 7 or later.

Microphone demo

The *microphone* demo requires the following components on the host PC side:

- USB or jack headphone, speaker or headset with built-in speaker.
- Sound Manager (accessible via menu *Start* > *Control Panel* > *Sound*).

The microphone demo is built using an audio function topology defined in the file `usbd_audio_dev_cfg.c` and composed of:

- 1 Input Terminal of type analog mic IN,
- 1 Output Terminal of type USB IN,
- 1 Feature Unit to manage volume and mute controls,
- 1 record AudioStreaming interface associated to the Input Terminal.

Refer to Figure - usbd_audio_dec_cfg.c - Typical Topologies Example in the *Audio Topology Configuration* page for a visual representation of this audio function.

Figure - Microphone Demo in the *Using the Audio Class Demo Application* page shows the principle of the microphone demo.

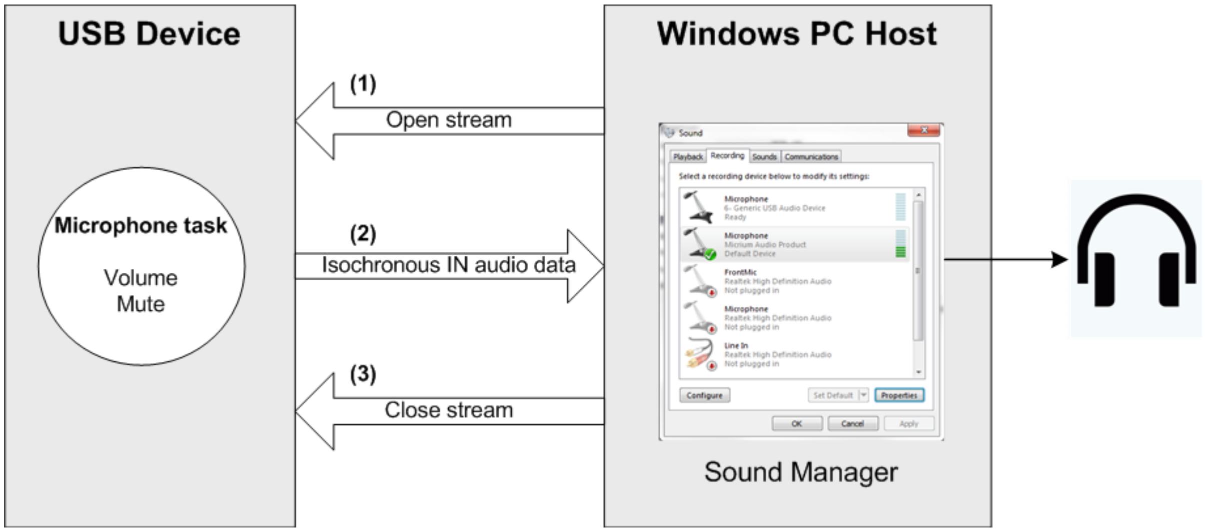


Figure - Microphone Demo

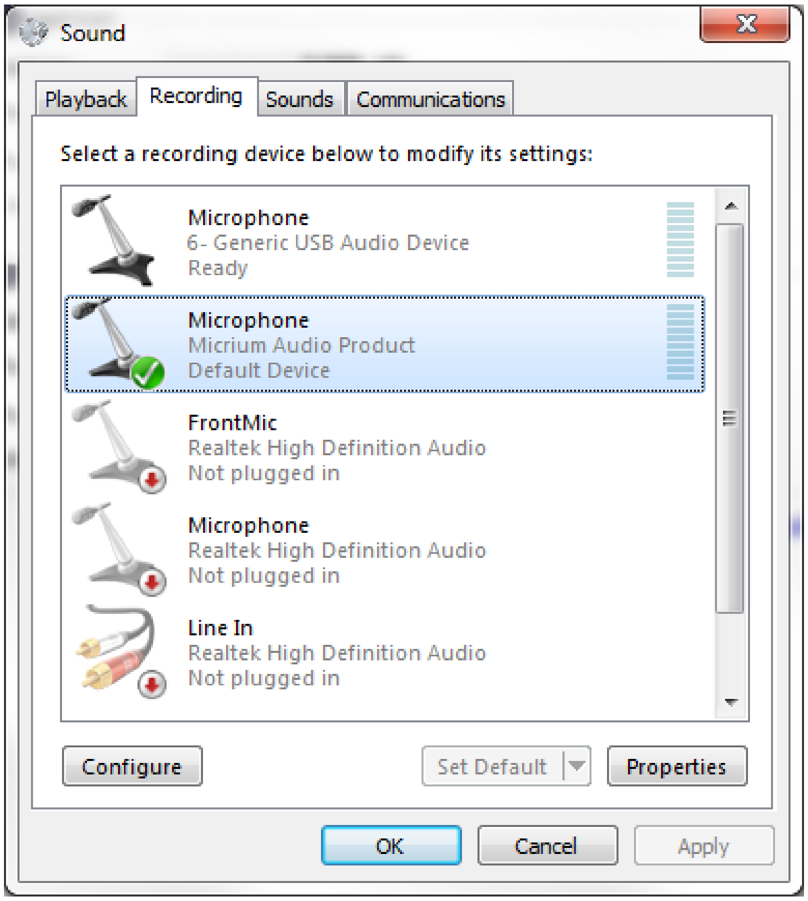
(1) The Windows audio driver opens the record stream by selecting the first operational AudioStreaming interface. This step is done automatically when the audio device is connected to the PC.

(2) The microphone task detects that the stream is open and starts sending pre-defined record data to the host. The record data corresponds to the waveform selected with the constant `APP_CFG_USBD_AUDIO_DRV_SIMULATION_DATA_WAVEFORM`. In fact, the audio class record task will take care of submitting record data via isochronous IN transfers (USBD_IsocTxAsync). The host will forward record data to a headphone for instance. You should hear the waveform (sinus, square, sawtooth or beep beep). If the host sends some requests to change the volume or to mute/unmute the stream, the microphone task will apply the volume or mute change on the record data accordingly.

(3) The Windows audio driver closes the stream by selecting the default AudioStreaming interface. This action is done only if you decide to disable the microphone from the Sound Manager.

Upon connection of your audio device, the simulated microphone device should appear in the *recording devices* list of the Sound Manager as shown in Figure - Sound Manager - Microphone in Recording Devices List in the *Using the Audio Class Demo Application* page.

In this example, the recording device is identified as "Micrium Audio Product" (`ProductStrPtr` field of `USBD_DEV_CFG` set to this string).



Select a recording device below to modify its settings:

Microphone
6- Generic USB Audio Device
Ready

Microphone
Micrium Audio Product
Default Device

FrontMic
Realtek High Definition Audio
Not plugged in

Microphone
Realtek High Definition Audio
Not plugged in

Line In
Realtek High Definition Audio
Not plugged in

Figure - Sound Manager - Microphone in Recording Devices List

In order to listen to the waveform signal, you need to ensure that:

- the volume level is different from 0 and the microphone is not muted. Select your microphone, click the button "Properties", go to the tab "Levels" and check the settings. It should look like Figure - Sound Manager - Microphone Levels in the *Using the Audio Class Demo Application* page.

- the playthrough feature is enabled. Select your microphone, click the button "Properties", go to the tab "Listen" and select "Listen to this device". Ensure that the Windows audio driver will playback the record data through your headphone by looking at the "Playback through this device" list (cf. Figure - Sound Manager - Microphone Playthrough in the *Using the Audio Class Demo Application* page).

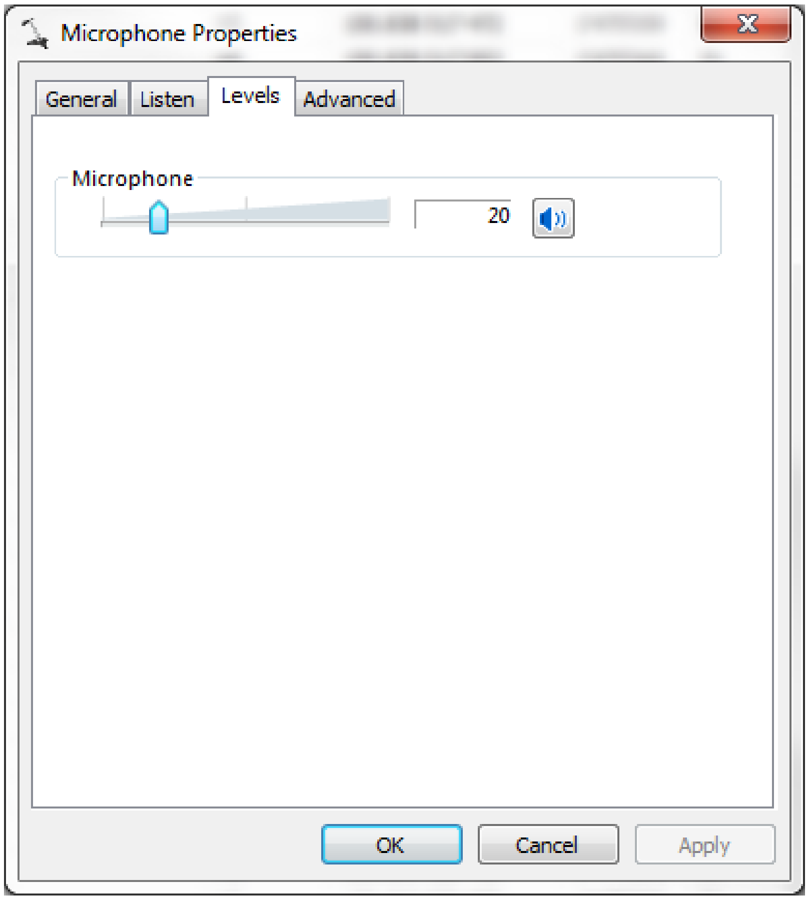
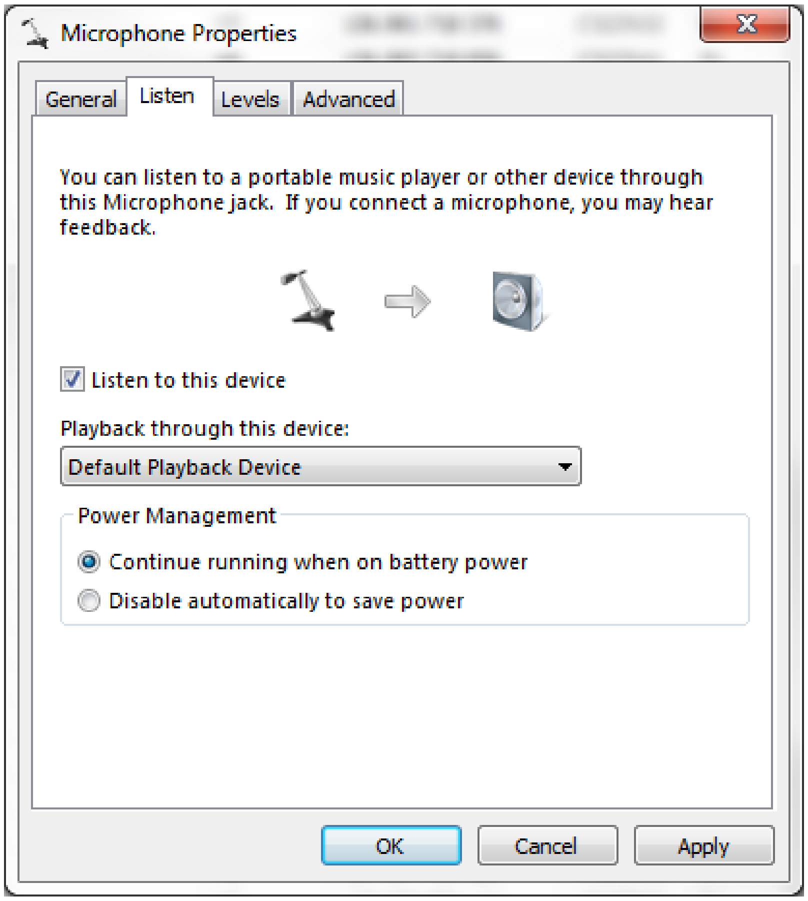


Figure - Sound Manager - Microphone Levels



You can listen to a portable music player or other device through this Microphone jack. If you connect a microphone, you may hear feedback.

[✓] Listen to this device

Playback through this device: Default Playback Device

Power Management

[● Continue running when on battery power]

○ Disable automatically to save power

Figure - Sound Manager - Microphone Playthrough

Loopback demo

The *loopback* demo requires the following components on the host PC side:

- USB or jack headphone, speaker or headset with built-in speaker.
- Music Player (for example, Windows Media Player).
- Sound Manager (accessible via menu *Start* > *Control Panel* > *Sound*).

The loopback demo is built using an audio function topology defined in the file `usbd_audio_dev_cfg.c` and composed of:

- Two Input terminals of type analog mic IN and USB OUT,

- Two Output terminals of type USB IN and speaker,
- Two Feature units to manage volume and mute controls for microphone and speaker parts.
- Two AudioStreaming interfaces (one record and one playback). Each associated to one of the Input terminals.

Refer to Figure - usbd_audio_dec_cfg.c - Typical Topologies Example in the *Audio Topology Configuration* page for a visual representation of this audio function.

Figure - Loopback Demo in the *Using the Audio Class Demo Application* page shows the principle of the loopback demo which can be seen as a simulated headset.

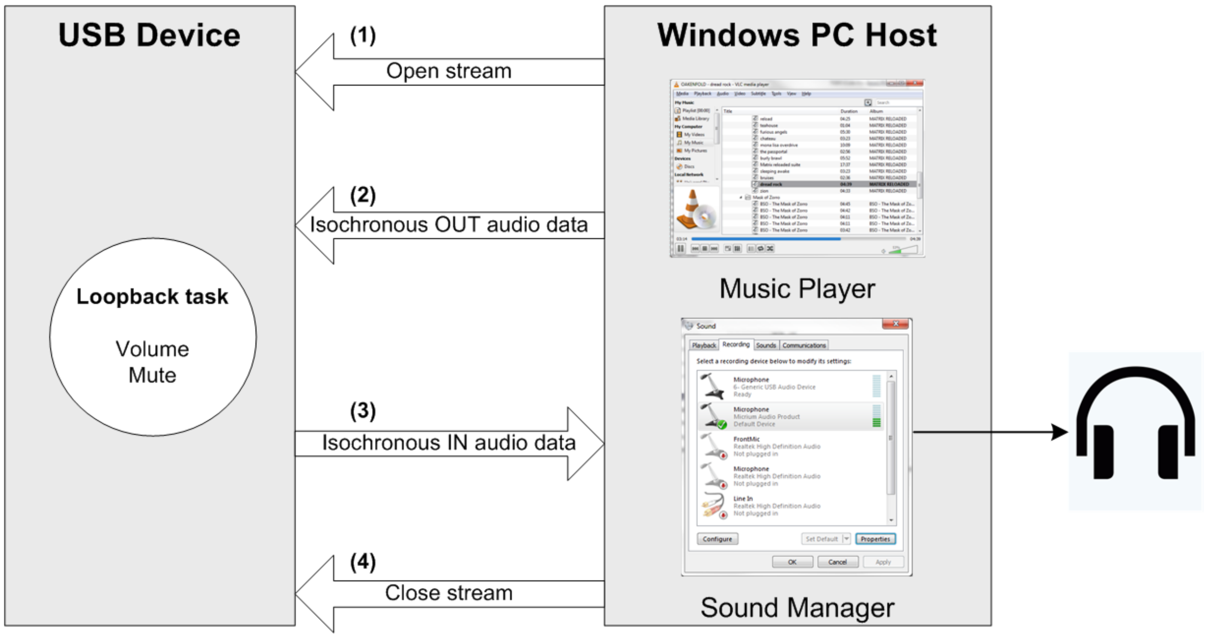


Figure - Loopback Demo

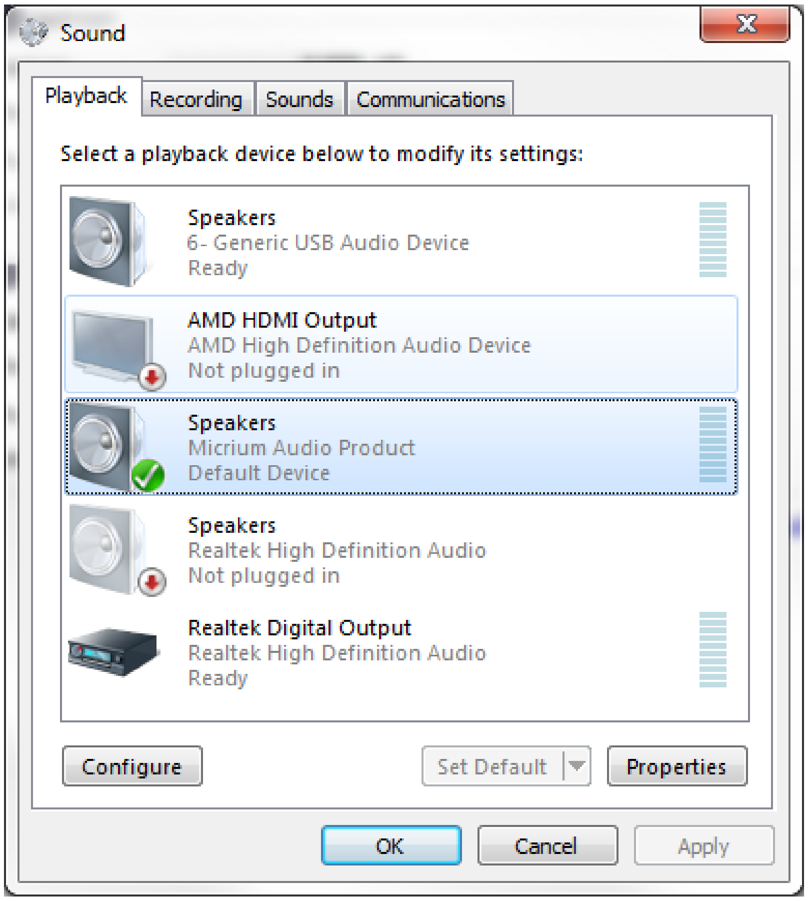
(1) The Windows audio driver opens the record and playback streams by selecting the first operational interface of each AudioStreaming (AS) interface. This step is done automatically for the microphone AS interface when the audio device is connected to the PC. For the speaker AS, you will have to ensure that it is enabled in the Sound Manager (cf. below).

(2) Both streams must be open in order to start the streams communication. The loopback task will basically perform two sequential operations seamlessly: processing playback stream and processing record stream. The loopback task detects that the playback stream is open and retrieves one of the isochronous OUT data buffers stored in the audio class. The playback buffer is stored in a circular buffer. Playback data comes from a music player playing songs. I f the host sends some requests to change the volume or to mute/unmute the playback stream, the loopback task will apply the volume or mute change on the playback data accordingly.

(3) The loopback task continues its execution by processing the record stream. If the record stream is open, it obtains a playback buffer from the circular buffer. This one becomes a record buffer. The loopback task passes the record buffer to the audio class which will take care of submitting record data via isochronous IN transfers . The host will forward record data to a headphone for instance. You should hear the song from the music player (if some settings explained below for the microphone are correct). If the host sends some requests to change the volume or to mute/unmute the record stream, the loopback task will apply the volume or mute change on the record data accordingly.

(4) The Windows audio driver closes streams by selecting the default AudioStreaming interface for the microphone and speaker. This action is done only if you decide to disable the microphone and speaker from the Sound Manager.

Upon connection of your audio device, the simulated headset device should appear in two lists. The microphone should be listed in the *recording devices* list of the Sound Manager as shown in Figure - Sound Manager - Microphone in Recording Devices List in the *Using the Audio Class Demo Application* page, whereas the speaker part should be listed in the *playback devices* list as shown in Figure - Sound Manager - Speaker in Playback Devices List in the *Using the Audio Class Demo Application* page. In this example, the playback and recording device are identified as "Micrium Audio Product" (`ProductStrPtr` field of `USBD_DEV_CFG` set to this string).



Select a playback device below to modify its settings:

Speakers
6- Generic USB Audio Device
Ready

AMD HDMI Output
AMD High Definition Audio Device
Not plugged in

Speakers
Micrium Audio Product
Default Device

Speakers
Realtek High Definition Audio
Not plugged in

Realtek Digital Output
Realtek High Definition Audio
Ready

Figure - Sound Manager - Speaker in Playback Devices List

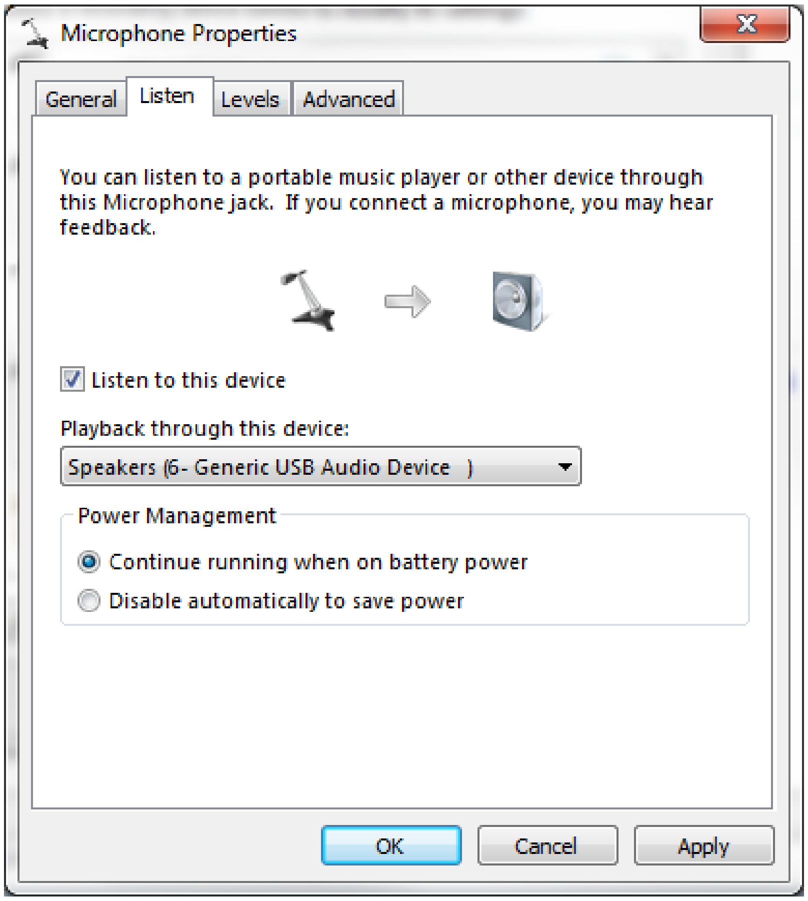
In order to listen to the song played by the music player, you need to ensure that:

- Speaker: the speaker appears in the list as the "Default Device" as shown in Figure - Sound Manager - Speaker in Playback Devices List in the *Using the Audio Class Demo Application* page. If it is not the case, right-click on the "Micrium Audio Product" speaker and select "Set as Default Device".

- Microphone: the volume level is different from 0 and the microphone is not muted. Refer to Figure - Sound Manager - Microphone Levels in the *Using the Audio Class Demo Application* page.

- Microphone: the playthrough feature is enabled. Select your microphone, click the button "Properties", go to the tab "Listen" and select "Listen to this device". Ensure that the Windows audio driver will playback the record data through your headphone by looking at the "Playback through this device" list (cf. Figure - Sound Manager - Microphone

Playthrough for Loopback Demo in the *Using the Audio Class Demo Application* page). Do not select "Default Playback Device" as it could be the "Micrium Audio Product" speaker. In that case you won't hear anything as the music player and the microphone share the same speaker of your audio device. Explicitly select another speaker device (for example, your jack headphone).



You can listen to a portable music player or other device through this Microphone jack. If you connect a microphone, you may hear feedback.

[✓] Listen to this device

Playback through this device:
Speakers (6- Generic USB Audio Device)

Power Management

[● Continue running when on battery power]
Disable automatically to save power

Figure - Sound Manager - Microphone Playthrough for Loopback Demo

Audio Class Configuration Guidelines

In order to optimize the usage of the audio class, there are a few places to pay attention to when configuring the audio class:

- Memory segment size: parameter `size` of `Mem_SegCreate()` or µC/LIB heap size: `LIB_MEM_CFG_HEAP_SIZE`
- µC/USB-Device general configuration for extra URBs (USB Request Block): `USBD_CFG_MAX_NBR_URB_EXTRA`
- Buffers allocated to each AudioStreaming interface: field `MaxBufNbr` of structure `USBD_AUDIO_STREAM_CFG` passed as argument to `USBD_Audio_AS_IF_Cfg`

The recommendations for these places are:

1. Buffers allocated for each AudioStreaming interface composing your audio function are allocated either from a dedicated memory segment created with `Mem_SegCreate()` or from the heap region defined by µC/LIB. Consequently, the parameter `size` of `Mem_SegCreate()` or the configuration constant `LIB_MEM_CFG_HEAP_SIZE` defining the heap region size must be set large enough to hold all playback and record buffers.

2. `USBD_CFG_MAX_NBR_URB_EXTRA` is used by the core layer to assign an URB to each isochronous transfer submitted to the core and that could be queued in a USB device driver. Certain USB device drivers implement a queuing mechanism allowing to queue several isochronous transfers for a given endpoint. If a USB device driver is capable of queuing transfers and in order to take advantage of audio streaming, the total number of allocated buffers for all AudioStreaming interfaces should be equal to `USBD_CFG_MAX_NBR_URB_EXTRA`. It will allow the playback and record tasks to queue each time all isochronous transfers they can. They will spend less time trying to re-submit an isochronous transfer if this one could not be queued. If the USB device driver can only accept one transfer at a time, it is not necessary that the total number of allocated buffers be equal to `USBD_CFG_MAX_NBR_URB_EXTRA`. In that case, you can specify the total number of buffers you want. The result is that playback and record tasks will attempt more often to retry isochronous transfers that cannot be queued.

3. The field `MaxBufNbr` of structure `USBD_AUDIO_STREAM_CFG` should be set accordingly following the two previous recommendations. Moreover,

Table - Audio Class Configuration Guidelines in the *Audio Class Configuration Guidelines* page presents some examples according to the type of audio application.

Constant	Value	Note
Playback only application (2 channels, 16 bit resolution, 48 kHz)		
`APP_CFG_USBD_AUDIO_PLAYBACK_NBR_BUF`	16u	Application constant that can be passed to the field `MaxBufNbr` of structure `USBD_AUDIO_STREAM_CFG`.
`USBD_CFG_MAX_NBR_URB_EXTRA`	16u	The USB device driver is able to queue isochronous transfers.
parameter `size` of `Mem_SegCreate()` `LIB_MEM_CFG_HEAP_SIZE`	-	With 2 channels, 16 bit resolution, 48 kHz, each playback buffer is 192 bytes which gives a total of 192 * 20 = 3072 bytes. The memory segment or heap should be set accordingly to accommodate the 3072 bytes required.
Record only application (1 channel, 16 bit resolution, 48 kHz)		
`APP_CFG_USBD_AUDIO_RECORD_NBR_BUF`	16u	Application constant that can be passed to the field `MaxBufNbr` of structure `USBD_AUDIO_STREAM_CFG` .
`USBD_CFG_MAX_NBR_URB_EXTRA`	0u	The USB device driver is not able to queue isochronous transfers. `USBD_CFG_MAX_NBR_URB_EXTRA` set to 0 should be avoided. The record and/or the playback tasks can spend more time re-submitting isochronous transfers that cannot be queued. The stream may be altered by some zero-packet length isochoronous transfers provoking some audible audio artifacts. The USB device driver should support at least double-buffering when dealing with audio and isochronous transfers.
parameter `size` of `Mem_SegCreate()` `LIB_MEM_CFG_HEAP_SIZE`	-	With 1 channel, 16 bit resolution, 48 kHz, each record buffer is 96 bytes which gives a total of 96 * 16 = 1536 bytes. The memory segment or heap should be set accordingly to accommodate the 1536 bytes required.
Playback and record application (playback: 2 channels, 16 bit resolution, 48 kHz; record: 1 channel, 16 bit resolution, 48 kHz)		
`APP_CFG_USBD_AUDIO_PLAYBACK_NBR_BUF`	16u	Application constant that can be passed to the field `MaxBufNbr` of structure `USBD_AUDIO_STREAM_CFG`.
`APP_CFG_USBD_AUDIO_RECORD_NBR_BUF`	16u	Application constant that can be passed to the field `MaxBufNbr` of structure `USBD_AUDIO_STREAM_CFG`.
`USBD_CFG_MAX_NBR_URB_EXTRA`	32u	The USB device driver is able to queue isochronous transfers.
parameter `size` of `Mem_SegCreate()` `LIB_MEM_CFG_HEAP_SIZE`	-	Each playback buffer is 192 bytes which gives a total of 192 * 16 = 3072 bytes and each record buffer is 96 bytes which gives a total of 96 * 16 = 1536 bytes. At least, 5760 bytes must be available from the memory segment or the heap for all audio buffers. More heap space can be necessary for all software resources needed by the USB device stack and other Micrium products used in your application.

Table - Audio Class Configuration Guidelines

Heap Size

μC/USB-Device uses the heap to allocate some software resources such as internal buffers. The core, classes and certain drivers allocate resources on the heap. Moreover, you must take into account that other Micrium products also allocate from the heap. Thus, its size must be set accordingly.

Another recommendation relates to the configuration of the maximum number of interfaces (constant `USBD_CFG_MAX_NBR_IF`) and alternate interfaces (constant `USBD_CFG_MAX_NBR_IF_ALT`) needed for your audio function. Assuming that the audio class is the only class used, these formula can be used to determine the maximum number of interfaces and alternates interfaces for the audio class:

`USBD_CFG_MAX_NBR_IF` = sum of [(1 AudioControl interface + N AudioStreaming interface)] from 1 to X times Audio Interface Collection (AIC)

`USBD_CFG_MAX_NBR_IF_ALT` = sum of [(1 AudioControl interface + N AudioStreaming interface * M alternate settings)] from 1 to X times Audio Interface Collection (AIC)

where N is in the range [1, 255] and M in the range [2, 255]

When using the built-in playback or record correction, you should pay attention to the value of the `MaxBufNbr` field of the structure `USBD_AUDIO_STREAM_CFG`. The size of the safe zone depends on t he number of streams buffers, set in the field `MaxBufNbr` . If you allocate more buffers for a given stream, the safe zone will be larger. Since the pre-buffering threshold for a stream is always (`MaxBufNbr` / 2), if the safe zone is large, any slight clock drift between the USB and codec clocks will be easily absorbed and the risk of reaching the under-run or overrun situation is reduced (cf. Figure - Playback Ring Buffers Queue Monitoring in the *Audio Class Stream Data Flow* page).

If you activate any stream correction (built-in or feedback), you should set the number of buffers, the field `MaxBufNbr`, to a multiple of 6. This will optimize the stream correction processing. You can set the field `MaxBufNbr` to one of these pre-defined constants:

- `USBD_AUDIO_STREAM_NBR_BUF_6`
- `USBD_AUDIO_STREAM_NBR_BUF_12`

- `USBD_AUDIO_STREAM_NBR_BUF_18`
- `USBD_AUDIO_STREAM_NBR_BUF_24`
- `USBD_AUDIO_STREAM_NBR_BUF_30`
- `USBD_AUDIO_STREAM_NBR_BUF_36`
- `USBD_AUDIO_STREAM_NBR_BUF_42`

Furthermore, if you have a playback stream, you should favor the feedback correction. Indeed, the feedback correction allows a correction more progressive as the host is doing the audio samples adjustment based on the device feedback for a given stream. It makes the correction smoother and prevent the device from trying to compensate on its side a possible USB and codec clocks drifting by software that could impact the correction performance.

Audio Peripheral Driver Guide

There are many audio codecs available on the market and each requires a driver to work with the audio class. The driver is referred as the Audio Peripheral Driver in the general audio class architecture. The amount of code necessary to port a specific audio codec to the audio class greatly depends on the codec's complexity.

Micrium does NOT develop audio codec drivers. It is your responsibility to develop the Audio Peripheral Driver for your audio hardware. Micrium provides a template of the Audio Peripheral Driver than can be used to as a starting point for your driver. You can also read the different sections below.

General Information

An Audio Peripheral Driver template containing empty functions is provided. It is located in the folder `\Micrium\Software\uC-USB-Device-V4\Class\Audio\Drivers\Template`. You can start from it to write your driver.

No particular memory interface is required by the audio peripheral driver model. Therefore, the audio peripheral may use the assistance of a Direct Memory Access (DMA) controller to transfer audio data.

It is **highly recommended** to use a DMA implementation of the driver as it will offload the CPU and ensure better overall audio performances.

Figure - Typical Audio Codec Interfacing a MCU in the *Audio Peripheral Driver Guide* page presents a typical stereo codec and how it interfaces with a microcontroller (MCU).

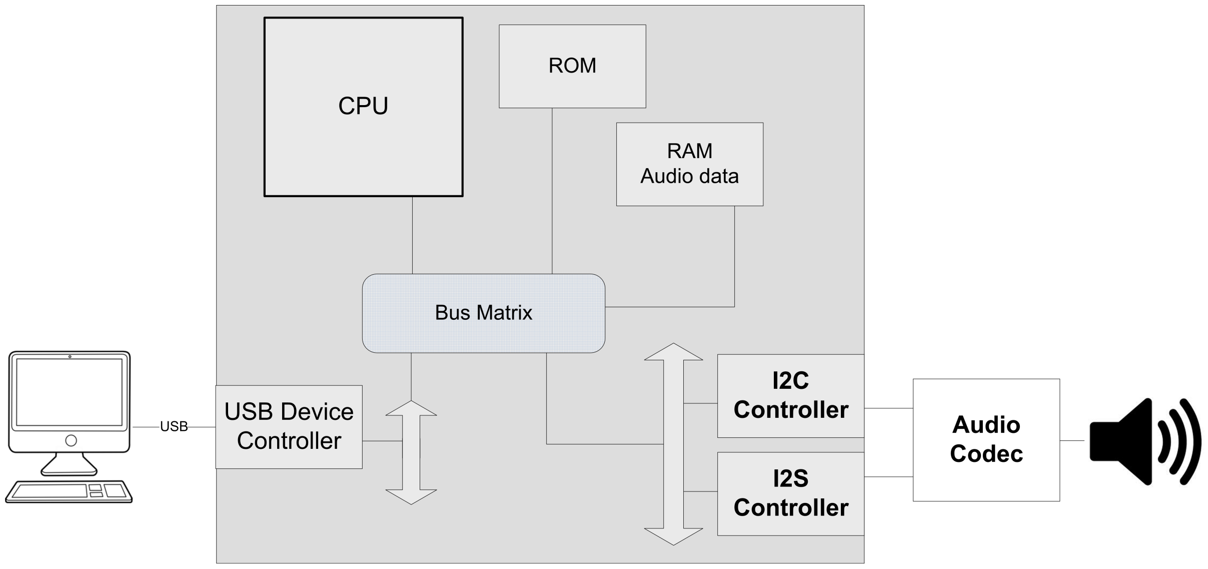


Figure - Typical Audio Codec Interfacing a MCU

An audio codec will usually have two interfaces with the microcontroller:

- One interface to configure and control the audio codec.This interface could be I^2C or SPI for instance.
- One interface to transfer audio data. This interface could be stereo audio I 2 S or any other serial data communication protocols.

As shown by the figure above, the audio peripheral driver may have to deal with two different peripherals of the MCU to communicate with the audio codec.

Memory Allocation

Memory allocation in the driver can be simplified by the use of memory allocation functions available from Micrium's µC/LIB module. µC/LIB's memory allocation functions provide allocation of memory from dedicated memory space or general purpose heap. The driver may use the pool functionality offered by µC/LIB. Memory pools use fixed-sized blocks that can be dynamically allocated and freed during application execution. Memory pools may be convenient to manage objects needed by the driver. The objects could be for instance data structures mandatory for DMA operations. For more information on using µC/LIB memory allocation functions, consult the µC/LIB documentation.

API

All audio peripheral drivers must declare different instances of the appropriate driver API structure as global variables within the source code. Each API structure is an ordered list of function pointers utilized by the audio class when device hardware services are required. Each structure will encompass some functions belonging to a category: common, Output Terminal, Feature Unit, Mixer Unit, Selector Unit and AudioStreaming (AS) interface. The API structure will then be passed to the appropriate `USBD_Audio_XX_Add()` functions. Theses different API structures offers two possibilities to handle the terminal and unit IDs management within a given codec driver function:

- either have one driver function for all terminals or units or AS interfaces. In that case, IDs must be managed.
- or one function per terminal or unit or AS. ID passed as argument of the driver function by the audio class can be ignored as there is a one-to-one relation between the function and the terminal or unit or AS.

Sample device driver API structures are shown below.

```
const  USBD_AUDIO_DRV_COMMON_API  USBD_Audio_DrvCommonAPI_Template = {
    USBD_Audio_DrvInit                                          (1)
};
const  USBD_AUDIO_DRV_AC_OT_API  USBD_Audio_DrvOT_API_Template = {
    USBD_Audio_DrvCtrlOT_CopyProtSet                            (2)
};
const  USBD_AUDIO_DRV_AC_FU_API  USBD_Audio_DrvFU_API_Template = {
    USBD_Audio_DrvCtrlFU_MuteManage,                            (3)
    USBD_Audio_DrvCtrlFU_VolManage,                             (4)
    USBD_Audio_DrvCtrlFU_BassManage,                            (5)
    USBD_Audio_DrvCtrlFU_MidManage,                             (6)
    USBD_Audio_DrvCtrlFU_TrebleManage,                          (7)
    USBD_Audio_DrvCtrlFU_GraphicEqualizerManage,                (8)
    USBD_Audio_DrvCtrlFU_AutoGainManage,                        (9)
    USBD_Audio_DrvCtrlFU_DlyManage,                             (10)
    USBD_Audio_DrvCtrlFU_BassBoostManage,                       (11)
    USBD_Audio_DrvCtrlFU_LoudnessManage                         (12)
};

const  USBD_AUDIO_DRV_AC_MU_API  USBD_Audio_DrvMU_API_Template = {
    USBD_Audio_DrvCtrlMU_CtrlManage                             (13)
};
const  USBD_AUDIO_DRV_AC_SU_API  USBD_Audio_DrvSU_API_Template = {
    USBD_Audio_DrvCtrlSU_InPinManage                            (14)
};
const  USBD_AUDIO_DRV_AS_API  USBD_Audio_DrvAS_API_Template = {
    USBD_Audio_DrvAS_SamplingFreqManage,                        (15)
    USBD_Audio_DrvAS_PitchManage,                               (16)
    USBD_Audio_DrvStreamStart,                                  (17)
    USBD_Audio_DrvStreamStop,                                   (18)
    USBD_Audio_DrvStreamRecordRx,                               (19)
    USBD_Audio_DrvStreamPlaybackTx                              (20)
};
```

Listing - Audio Peripheral Driver Interface API

(1) Audio peripherals initialization.

(2) Set Copy Protection Level.

(3) Get or set m ute state.

(4) Get or set volume level.

(5) Get or set bass level.

(6) Get or set middle level.

(7) Get or set treble level.

(8) Get or set graphical equalizer level.

(9) Get or set auto gain state.

(10) Get or set delay value.

(11) Get or set bass boost state.

(12) Get or set loudness state.

(13) Get or set mix status.

(14) Get or set selected Input Pin of a particular Selector Unit.

(15) Get or set sampling frequency.

(16) Get or set pitch state.

(17) Start record or playback stream.

(18) Stop record or playback stream.

(19) Get a ready record buffer from codec.

(20) Provide a ready playback buffer to codec.

The audio peripheral driver functions can be divided into three API groups as shown in the Table - Audio Peripheral Driver API Groups in the *Audio Peripheral Driver Guide* page.

Group	Function	Required?	Notes
Initialization	`USBD_Audio_DrvInit`	Yes	
AudioControl interface	`USBD_Audio_DrvCtrlOT_CopyProtSet()`	No	Relates to Output Terminal control.
	`USBD_Audio_DrvCtrlFU_MuteManage`	Yes	Relates to Feature Unit controls.
	`USBD_Audio_DrvCtrlFU_VolManage()`	Yes	Relates to Feature Unit controls.
	`USBD_Audio_DrvCtrlFU_BassManage()`	No	Relates to Feature Unit controls.
	`USBD_Audio_DrvCtrlFU_MidManage()`	No	Relates to Feature Unit controls.
	`USBD_Audio_DrvCtrlFU_TrebleManage()`	No	Relates to Feature Unit controls.
	`USBD_Audio_DrvCtrlFU_GraphicEqualizerManage()`	No	Relates to Feature Unit controls.
	`USBD_Audio_DrvCtrlFU_AutoGainManage`	No	Relates to Feature Unit controls.
	`USBD_Audio_DrvCtrlFU_DlyManage()`	No	Relates to Feature Unit controls.
	`USBD_Audio_DrvCtrlFU_BassBoostManage`	No	Relates to Feature Unit controls.
	`USBD_Audio_DrvCtrlFU_LoudnessManage`	No	Relates to Feature Unit controls.
	`USBD_Audio_DrvCtrlMU_CtrlManage()`	No	Relates to Mixer Unit control.
	`USBD_Audio_DrvCtrlSU_InPinManage`	No	Relates to Selector Unit control.
AudioStreaming (AS) interface	`USBD_Audio_DrvAS_SamplingFreqManage`	Yes	Relates to AS endpoint controls.
	`USBD_Audio_DrvAS_PitchManage`	No	Relates to AS endpoint controls.
	`USBD_Audio_DrvStreamStart`	Yes if at least one record or playback AS interface defined.	
	`USBD_Audio_DrvStreamStop`	Yes if at least one record or playback AS interface defined.	

	`USBD_Audio_DrvStreamRecordRx`	Yes if at least one record AS interface defined.	
	`USBD_Audio_DrvStreamPlaybackTx`	Yes if at least one playback AS interface defined.	

Table - Audio Peripheral Driver API Groups

Optional functions can be declared as null pointers if the audio chip does not support the associated functionality.

It is the audio peripheral driver developers' responsibility to ensure that the required functions listed within the API are properly implemented and that the order of the functions within the API structure is correct.

Audio peripheral driver API function names may not be unique. Name clashes between audio peripheral drivers are avoided by never globally prototyping device driver functions and ensuring that all references to functions within the driver are obtained by pointers within the API structure. The developer may arbitrarily name the functions within the source file so long as the API structure is properly declared. The user application should never need to call API functions. Unless special care is taken, calling device driver functions may lead to unpredictable results due to reentrancy.

The details of each audio peripheral driver API function are described in the Audio Peripheral Driver API Reference.

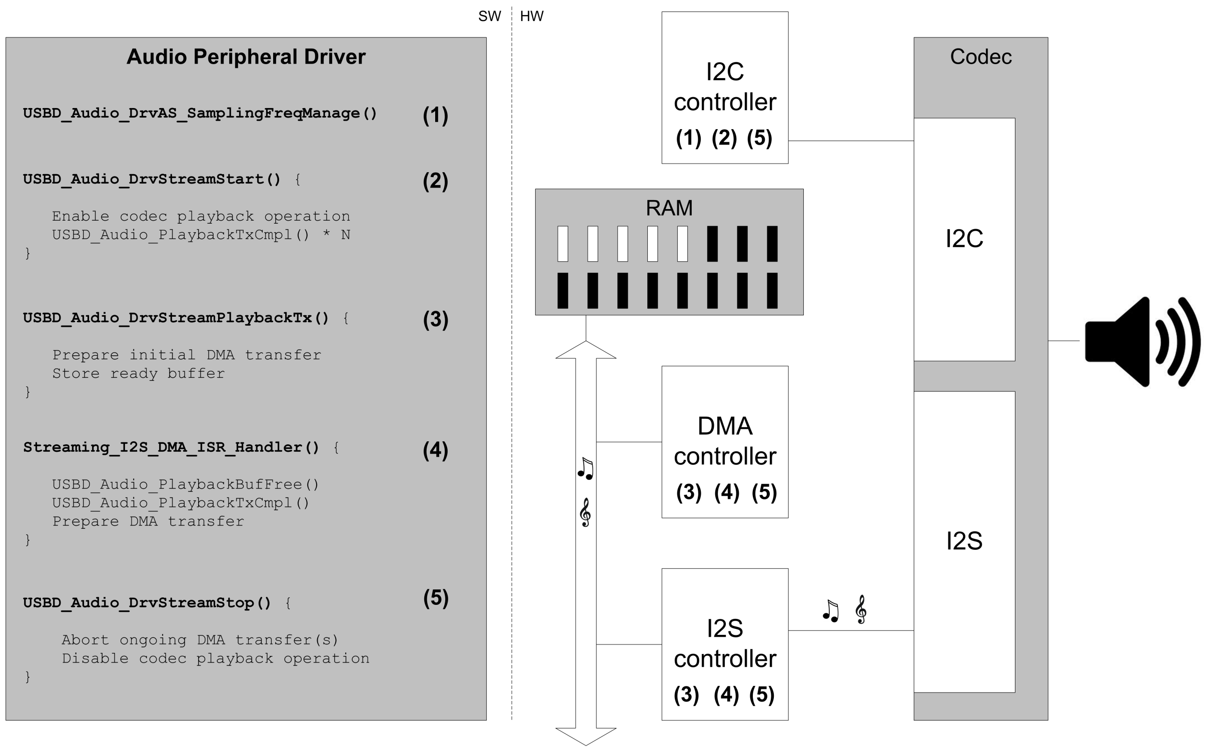
Using Audio Processing Stream Functions

The audio peripheral driver has access to stream API offered by the Audio Processing module presented in Table - Audio Processing Module Stream API in the *Audio Peripheral Driver Guide* page. Basically, this stream API allows the audio peripheral driver to get buffers to transfer audio data to/from an audio codec or any other types of audio chip.

Function	Description
`USBD_Audio_RecordBufGet`	Gets a buffer from an AS interface pool.
`USBD_Audio_RecordRxCmpl`	Signals to the record task a record buffer is ready.
`USBD_Audio_PlaybackTxCmpl`	Signals the end of the audio transfer to the playback task.
`USBD_Audio_PlaybackBufFree`	Updates one of the ring buffer queue indexes.

Table - Audio Processing Module Stream API

In order to better understand the use of this stream API, we will consider the typical audio stereo codec configuration shown by Figure - Typical Audio Codec Interfacing a MCU in the *Audio Peripheral Driver Guide* page. Moreover, a DMA controller used by the I^{2}S controller will be assumed. Figure - Playback Stream Functions in the *Audio Peripheral Driver Guide* page summarizes the use of stream functions for a playback stream. Please refer to Figure - Playback Stream Dataflow in the *Audio Class Stream Data Flow* page as a complement to know what is happening in the Audio Processing module.


SW
HW
Audio Peripheral Driver
I2C controller (1) (2) (5)
RAM
DMA controller (3) (4) (5)
I2S controller (3) (4) (5)
Codec
I2C
I2S

```
USBD_Audio_DrvAS_SamplingFreqManage()                    (1)

USBD_Audio_DrvStreamStart() {                            (2)
   Enable codec playback operation
   USBD_Audio_PlaybackTxCmpl() * N
}

USBD_Audio_DrvStreamPlaybackTx() {                       (3)
   Prepare initial DMA transfer
   Store ready buffer
}

Streaming_I2S_DMA_ISR_Handler() {                        (4)
   USBD_Audio_PlaybackBufFree()
   USBD_Audio_PlaybackTxCmpl()
   Prepare DMA transfer
}

USBD_Audio_DrvStreamStop() {                             (5)
    Abort ongoing DMA transfer(s)
    Disable codec playback operation
}
```

Figure - Playback Stream Functions

(1) The host has opened the stream by selecting the operational AS interface. It then sets the sampling frequency (for instance, 48 kHz). The function `USBD_Audio_DrvCtrlAS_SamplingFreqManage()` will be called for that operation. The sampling frequency is configured by accessing some codec registers. The register access will be accomplished by sending several I^2C commands.

(2) Once the playback stream priming is completed within the Audio Processing module, that is a certain number of audio buffers has been accumulated, the function `USBD_Audio_DrvStreamStart` is called. Usually, you may have to enable playback operations within the codec through some registers configuration. Here again, I^2C controller will be used. The function `USBD_Audio_PlaybackTxCmpl()` is called by the driver to signal the audio transfer completion. The driver can call `USBD_Audio_PlaybackTxCmpl()` up to the number of buffers it can queue.

The audio peripheral driver should support at least the double-buffering to optimize the playback stream processing.

(3) The playback task will receive an AudioStreaming interface handle and will submit to the audio peripheral driver a ready buffer by calling `USBD_Audio_DrvStreamPlaybackTx` . The initial DMA transfer will be prepared with the first ready buffer. Note that the driver should start the initial DMA transfer after accumulating at least two ready buffers. This allows to start a sort of pipeline in which the audio peripheral driver won't wait after the playback task for providing a ready buffer to prepare the next DMA transfer. Once the pipeline is launched, any subsequent call to `USBD_Audio_DrvStreamPlaybackTx()` should store the ready buffer. Any buffer memory management method may be used to store the ready buffer (for instance, double-buffering, circular buffer, etc.).

Depending on the DMA controller, you may have to configure some registers and/or a DMA descriptor in order to describe the transfer. The DMA controller moves the audio data from the memory to the I^2S controller. This one will forward the data to the codec that will play audio data to the speaker.

(4) A DMA interrupt will be fired upon transfer completion. An ISR associated to this interrupt is called. This ISR processes the DMA transfer completion by freeing the consumed buffer. For that, the function `USBD_Audio_PlaybackBufFree()` is called. This

function updates one of the indexes of the ring buffer queue. The ISR continues by signaling to the playback task that the audio transfer has finished with `USBD_Audio_PlaybackTxCmpl` . Once again, the playback will provide a ready buffer via

`USBD_Audio_DrvStreamPlaybackTx()` as described in step (2). The ISR will get a new ready buffer from its internal buffer storage. A new DMA transfer is prepared and started. If no playback buffer is available from the internal storage, you may have to play a silence buffer to keep the driver in sync with audio class, that is you want to continue receiving DMA transfer completion interrupt to re-signal the audio transfer completion to the playback task. The silence buffer is filled with zeros interpreted by the codec as silence. The silence buffer can be allocated and initialized in the function `USBD_Audio_DrvInit()` .

> The DMA implementation in this example processes the playback buffers one after the other using a single interrupt. Depending on your DMA controller, it may be possible to optimize the performance by using several DMA channels. In that case, you could pipeline the DMA transfers. The DMA controller may also offer to link DMA descriptors. In that case, you could get several ready buffers and link several DMA descriptors.

(5) The host decides to stop the stream. The function `USBD_Audio_DrvStreamStop` is called. You should abort any ongoing DMA transfers. You don't have to call `USBD_Audio_PlaybackBufFree()` to free any aborted buffers nor to free ready buffers stored internally in the driver and not yet processed. The buffers are implicitly freed by the audio class during the ring buffer queue reset. You can also disable the playback operation on the codec if it is needed.

Figure - Record Stream Functions in the *Audio Peripheral Driver Guide* page summarizes the use of stream functions for a record stream. Please refer to Figure - Record Stream Dataflow in the *Audio Class Stream Data Flow* page as a complement to know that is happening in the Audio Processing module.

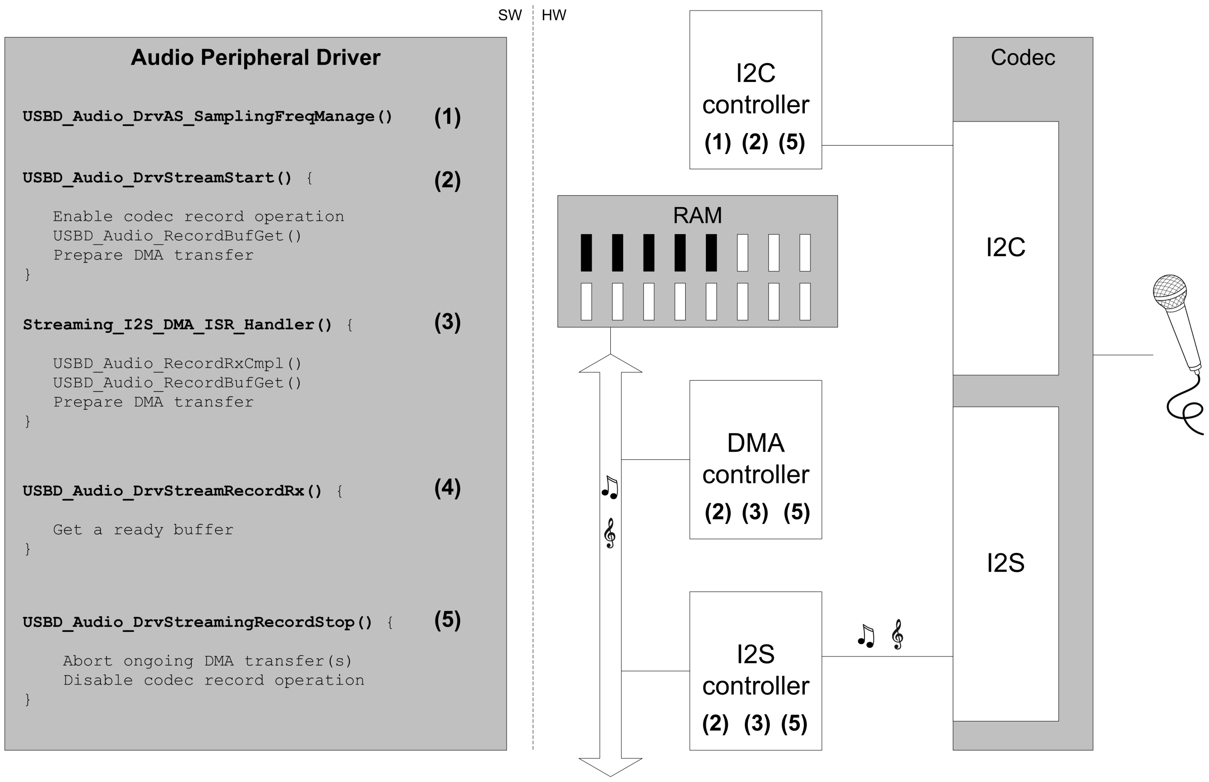

SW
HW
Audio Peripheral Driver
USBD_Audio_DrvAS_SamplingFreqManage() (1)
USBD_Audio_DrvStreamStart() { (2)
Enable codec record operation
USBD_Audio_RecordBufGet()
Prepare DMA transfer
}
Streaming_I2S_DMA_ISR_Handler() { (3)
USBD_Audio_RecordRxCmpl()
USBD_Audio_RecordBufGet()
Prepare DMA transfer
}
USBD_Audio_DrvStreamRecordRx() { (4)
Get a ready buffer
}
USBD_Audio_DrvStreamingRecordStop() { (5)
Abort ongoing DMA transfer(s)
Disable codec record operation
}
I2C controller (1) (2) (5)
RAM
DMA controller (2) (3) (5)
I2S controller (2) (3) (5)
Codec
I2C
I2S

Figure - Record Stream Functions

(1) The host has opened the stream by selecting the operational AS interface. It then sets the sampling frequency (for instance, 48 kHz). The function `USBD_Audio_DrvCtrlAS_SamplingFreqManage()` will be called for that operation. The sampling frequency is configured by accessing some codec registers. The register access will be accomplished by sending several I^{2}C commands.

(2) The Audio Processing will call the function `USBD_Audio_DrvStreamStart()` to start record operations on the codec side. Operations consists in enabling record operations within the codec through some registers configuration. The I^{2}C controller will be used for that. Then, the function `USBD_Audio_RecordBufGet()` is called by the driver to obtain an empty buffer. This function also specifies the buffer length. The driver does not have to figure out how many bytes is needed depending on the sampling frequency the number of channels and the bit resolution. This is taken into account by the Audio Processing layer. For sampling frequencies such 22.050 kHz, 44.1 kHz not producing an integer number of audio samples per milliseconds, a data rate adjustment is used (refer to Record Stream for more details about this data rate adjustment). With all the buffer's

information, you should prepare the initial DMA read transfer. Depending on the DMA controller, you may have to configure some registers and/or a DMA descriptor in order to describe the transfer. The DMA controller moves the audio data from the I^{2}S controller to the memory.

> If the DMA offers multiple channels or is able to link several DMA descriptors, you can call `USBD_Audio_RecordBufGet()` to obtain several buffers.

(3) A DMA interrupt will be fired upon transfer completion. An ISR associated to this interrupt is called. This ISR processes the DMA transfer completion by signaling to the record task that a buffer is ready with the function `USBD_Audio_RecordRxCmpl` . The ready buffer should be stored in an internal buffer storage. Any buffer memory management method may be used to store the ready buffer (for instance, double-buffering, circular buffer, etc.). The ISR continues by getting a new empty buffer with `USBD_Audio_RecordBufGet()` . A new DMA transfer is prepared and started. If no empty record buffer is available after calling `USBD_Audio_RecordBufGet()`, that is a null pointer is returned, you may have to get some record data using a dummy buffer to keep the driver in sync with audio class, that is you want to continue receiving DMA transfer completion interrupt to re-attempt to get an empty buffer. The record data stored in the dummy buffer is basically lost. The dummy buffer can be allocated in the function `USBD_Audio_DrvInit()` .

> The audio peripheral driver should support at least the double-buffering to optimize the record stream processing.

> The DMA implementation in this example processes the record buffers one after the other using a single interrupt. Depending on your DMA controller, it may be possible to optimize the performance by using several DMA channels. In that case, you could pipeline the DMA transfers. The DMA controller may also offer to link DMA descriptors. In that case, you could obtain several empty record buffers with `USBD_Audio_RecordBufGet()` and link several DMA descriptors.

(4) Upon reception of the signal, the record task will call the function `USBD_Audio_DrvStreamRecordRx` . It will get a ready buffer from the driver's internal

buffer storage and submit it to the USB side.

(5) The host decides to stop the stream. The function `USBD_Audio_DrvStreamStop()` is called. You should abort any ongoing DMA transfers. You can also disable the record operation on the codec if it is needed.

Statistics

As described in the section Audio Statistics, the audio class offered some stream statistics that may be useful during your development. An audio statistics structure (`USBD_AUDIO_STAT`) specific to each AS interface can be retrieved by the application and consulted during debugging. Table - USBD_AUDIO_STAT Structure Fields Description in the *Audio Statistics* page describes all the fields of `USBD_AUDIO_STAT`. Among them, there are four interesting for the driver:

- `AudioDrv_Playback_DMA_NbrXferCmpl`
- `AudioDrv_Playback_DMA_NbrSilenceBuf`
- `AudioDrv_Record_DMA_NbrXferCmpl`
- `AudioDrv_Record_DMA_NbrDummyBuf`

You can use the macro `AUDIO_DRV_STAT_INC()` by specifying an AS handle and the name of the field to update statistics. Listing - AUDIO_DRV_STAT_INC() Usage in the *Audio Peripheral Driver Guide* page shows an example of `AUDIO_DRV_STAT_INC()` usage.

```
 static  void  Streaming_I2S_DMA_ISR_Handler (CPU_INT08U  ch)
{
    USBD_AUDIO_DRV_DATA  *p_drv_data;
    CPU_INT08U           *p_buf;
    CPU_INT16U            buf_len;


    p_drv_data =  AudioDrvDataPtr;

    ...
    if (DMA write interrupt) {

        ...
        p_buf = Codec_PlaybackCircularBufGet(p_drv_data,
                                             &buf_len);
        if (p_buf != (CPU_INT08U *)0) {
                                                                 (1)
            USBD_AUDIO_DRV_STAT_INC(DMA_AsHandleTbl[ch], AudioDrv_Playback_DMA_NbrXferCmpl);

            /* $$$$ Prepare a DMA transfer. */
        } else {
            /* $$$$ Prepare a DMA transfer to play a silence buffer. */
                                                                 (2)
            USBD_AUDIO_DRV_STAT_INC(DMA_AsHandleTbl[ch], AudioDrv_Playback_DMA_NbrSilenceBuf);
        }
        ...
    }
    if (DMA write interrupt) {

        ...
        p_buf = (CPU_INT08U *)USBD_Audio_RecordBufGet(DMA_AsHandleTbl[ch],
                                                      &buf_len);
        if (p_buf != (CPU_INT08U *)0) {
                                                                 (3)
            USBD_AUDIO_DRV_STAT_INC(DMA_AsHandleTbl[ch], AudioDrv_Record_DMA_NbrXferCmpl);

            /* $$$$ Prepare a DMA transfer. */
        } else {
            /* $$$$ Prepare a DMA transfer with the dummy record buffer to keep in sync with audio
class. */
                                                                 (4)
            USBD_AUDIO_DRV_STAT_INC(DMA_AsHandleTbl[ch], AudioDrv_Record_DMA_NbrDummyBuf);
        }
        ...
    }
    ...
}
```

Listing - AUDIO_DRV_STAT_INC() Usage

(1) You can count a playback DMA transfer completed once you receive the interrupt indicating transfer completion. You can increase the counter `AudioDrv_Playback_DMA_NbrXferCmpl` if a new playback buffer has been successfully obtained as shown or you could increase it before getting a ready buffer from the internal storage. In that case, you will also count DMA transfers using the silence buffer.

(2) If no buffer is available, you may have to play a silence buffer to keep in sync with the

audio class. In that case, increase the counter `AudioDrv_Playback_DMA_NbrSilenceBuf` .

(3) You can count a record DMA transfer completed once you receive the interrupt indicating transfer completion. You can increase the counter `AudioDrv_Record_DMA_NbrXferCmpl` if a new empty record buffer has been successfully obtained as shown or you could increase it before the function `USBD_Audio_RecordBufGet()` . In that case, you will also count DMA transfer using the dummy buffer.

(4) If no empty buffer is available, you may have to use a dummy buffer to get record data and to keep in sync with the audio class. In that case, increase the counter `AudioDrv_Record_DMA_NbrDummyBuf` counter.

Porting the Audio Class to an RTOS

The audio class uses its own RTOS abstraction layer providing specific services needed by the two internal tasks, *playback* and *record*. Both tasks requires a queue to process certain types of messages. The playback task will receive events each time an audio transfer has completed. The record task will receive AudioStreaming requests to retrieve ready buffers from the Audio Peripheral driver and submit them to the USB device driver. A delay used by the playback and the record tasks in certain error conditions is also available from the audio RTOS layer. Two different lock mechanisms are also utilized to protect each AudioStreaming's structure and ring buffer queue.

By default, Micrium will provide an RTOS layer for both C/OS-II and C/OS-III. However, it is possible to create your own RTOS layer. Your layer will need to implement the functions listed in Table - OS Layer API Summary in the *Porting the Audio Class to an RTOS* page. For a complete API description, see the Audio API Reference.

Function name	Operation
`USBD_Audio_OS_Init()`	Initializes all internal members / tasks.
`USBD_Audio_OS_AS_IF_LockCreate()`	Creates an OS resource to use as an AudioStreaming interface lock.
`USBD_Audio_OS_AS_IF_LockAcquire()`	Waits for an AudioStreaming interface to become available and acquire its lock.
`USBD_Audio_OS_AS_IF_LockRelease()`	Releases an AudioStreaming interface lock.
`USBD_Audio_OS_RingBufQLockCreate()`	Creates an OS resource to use as a stream ring buffer queue lock.
`USBD_Audio_OS_RingBufQLockAcquire()`	Waits for a stream ring buffer queue to become available and acquire its lock.
`USBD_Audio_OS_RingBufQLockRelease()`	Releases a stream ring buffer queue lock.
`USBD_Audio_OS_RecordReqPost`	Posts a request into the record task's queue.
`USBD_Audio_OS_RecordReqPend`	Pends on a request from the record task's queue.
`USBD_Audio_OS_PlaybackReqPost`	Posts a request into the playback task's queue.
`USBD_Audio_OS_PlaybackReqPend`	Pends on a request from the playback task's queue.
`USBD_Audio_OS_DlyMs()`	Delays calling task for a certain duration expressed in milliseconds.
`USBD_Audio_OS_RecordTask()`	Task processing record streams. Refer to Audio Class Stream Data Flow for more details about this task.
`USBD_Audio_OS_PlaybackTask()`	Task processing playback streams. Refer to Audio Class Stream Data Flow for more details about this task.

Table - OS Layer API Summary

OS Tick Rate

Whenever possible, `USBD_Audio_OS_DlyMs` should provide a delay with a 1 ms granularity. That is t he OS tick rate should be set to produce at least 1 tick per millisecond.. It will improve the audio class tasks scheduling as audio class works on a 1 ms frame basis. Moreover, a retry mechanism is implemented in the playback and record tasks in case a transfer cannot be queued on a given endpoint. The playback or record task waits 1 ms between each attempt before re-transmitting the transfer.

Communications Device Class

This chapter describes the Communications Device Class (CDC) class and the associated CDC subclass supported by C/USB-Device. C/USB-Device currently supports the Abstract Control Model (ACM) subclass, which is especially used for serial emulation.

The CDC and the associated subclass implementation complies with the following specifications:

- *Universal Serial Bus, Class Definitions for Communications Devices, Revision 1.2*, November 3 2010.

- *Universal Serial Bus, Communications, Subclass for PSTN Devices, Revision 1.2*, February 9 2007.

CDC includes various telecommunication and networking devices. Telecommunication devices encompass analog modems, analog and digital telephones, ISDN terminal adapters, etc. Networking devices contain, for example, ADSL and cable modems, Ethernet adapters and hubs. CDC defines a framework to encapsulate existing communication services standards, such as V.250 (for modems over telephone network) and Ethernet (for local area network devices), using a USB link. A communication device is in charge of device management, call management when needed and data transmission. CDC defines seven major groups of devices. Each group belongs to a model of communication which may include several subclasses. Each group of devices has its own specification document besides the CDC base class. The seven groups are:

- Public Switched Telephone Network (PSTN), devices including voiceband modems, telephones and serial emulation devices.

- Integrated Services Digital Network (ISDN) devices, including terminal adaptors and telephones.

- Ethernet Control Model (ECM) devices, including devices supporting the IEEE 802 family (for instance cable and ADSL modems, WiFi adaptors).

- Asynchronous Transfer Mode (ATM) devices, including ADSL modems and other devices connected to ATM networks (workstations, routers, LAN switches).

- Wireless Mobile Communications (WMC) devices, including multi-function communications handset devices used to manage voice and data communications.
- Ethernet Emulation Model (EEM) devices which exchange Ethernet-framed data.
- Network Control Model (NCM) devices, including high-speed network devices (High Speed Packet Access modems, Line Terminal Equipment)

CDC Class Overview

A CDC device is composed of several interfaces to implement a certain function, that is communication capability. It is formed by the following interfaces:

- Communications Class Interface (CCI)
- Data Class Interface (DCI)

A CCI is responsible for the device management and optionally the call management. The device management enables the general configuration and control of the device and the notification of events to the host. The call management enables calls establishment and termination. Call management might be multiplexed through a DCI. A CCI is mandatory for all CDC devices. It identifies the CDC function by specifying the communication model supported by the CDC device. The interface(s) following the CCI can be any defined USB class interface, such as Audio or a vendor-specific interface. The vendor-specific interface is represented specifically by a DCI.

A DCI is responsible for data transmission. The data transmitted and/or received do not follow a specific format. Data could be raw data from a communication line, data following a proprietary format, etc. All the DCIs following the CCI can be seen as subordinate interfaces.

A CDC device must have at least one CCI and zero or more DCIs. One CCI and any subordinate DCI together provide a feature to the host. This capability is also referred to as a function. In a CDC composite device, you could have several functions. And thus, the device would be composed of several sets of CCI and DCI(s) as shown in Figure - CDC Composite Device in the *CDC Class Overview* page.

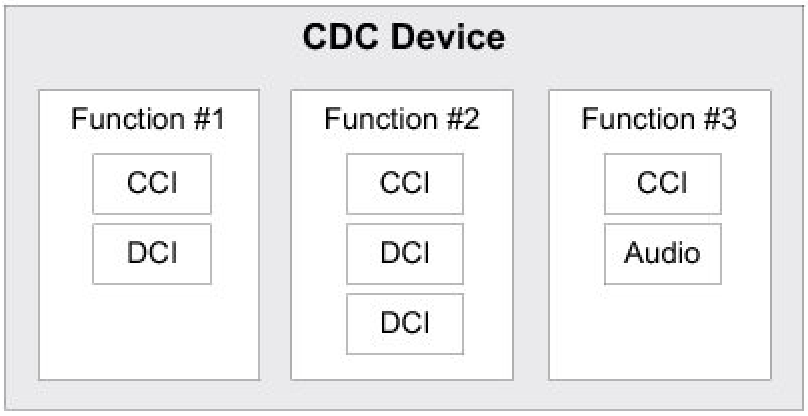


Figure - CDC Composite Device

A CDC device is likely to use the following combination of endpoints:

- A pair of control IN and OUT endpoints called the default endpoint.
- An optional bulk or interrupt IN endpoint.
- A pair of bulk or isochronous IN and OUT endpoints.

Table - CDC Endpoint Usage in the *CDC Class Overview* page indicates the usage of the different endpoints and by which interface of the CDC they are used:

Endpoint	Direction	Interface	Usage
Control IN	Device-to-host	CCI	Standard requests for enumeration, class-specific requests, device management and optionally call management.
Control OUT	Host-to-device	CCI	Standard requests for enumeration, class-specific requests, device management and optionally call management.
Interrupt or bulk IN	Device-to-host	CCI	Events notification, such as ring detect, serial line status, network status.
Bulk or isochronous IN	Device-to-host	DCI	Raw or formatted data communication.
Bulk or isochronous OUT	Host-to-device	DCI	Raw or formatted data communication.

Table - CDC Endpoint Usage

Most communication devices use an interrupt endpoint to notify the host of events.

Isochronous endpoints should not be used for data transmission when a proprietary protocol relies on data retransmission in case of USB protocol errors. Isochronous communication can inherently loose data since it has no retry mechanisms.

The seven major models of communication encompass several subclasses. A subclass describes the way the device should use the CCI to handle the device management and call management. Table - CDC Subclasses in the *CDC Class Overview* page shows all the possible subclasses and the communication model they belong to.

Subclass	Communication model	Example of devices using this subclass
Direct Line Control Model	PSTN	Modem devices directly controlled by the USB host
Abstract Control Model	PSTN	Serial emulation devices, modem devices controlled through a serial command set
Telephone Control Model	PSTN	Voice telephony devices
Multi-Channel Control Model	ISDN	Basic rate terminal adaptors, primary rate terminal adaptors, telephones
CAPI Control Model	ISDN	Basic rate terminal adaptors, primary rate terminal adaptors, telephones
Ethernet Networking Control Model	ECM	DOC-SIS cable modems, ADSL modems that support PPPoE emulation, Wi-Fi adaptors (IEEE 802.11-family), IEEE 802.3 adaptors
ATM Networking Control Model	ATM	ADSL modems
Wireless Handset Control Model	WMC	Mobile terminal equipment connecting to wireless devices
Device Management	WMC	Mobile terminal equipment connecting to wireless devices
Mobile Direct Line Model	WMC	Mobile terminal equipment connecting to wireless devices
OBEX	WMC	Mobile terminal equipment connecting to wireless devices
Ethernet Emulation Model	EEM	Devices using Ethernet frames as the next layer of transport. Not intended for routing and Internet connectivity devices
Network Control Model	NCM	IEEE 802.3 adaptors carrying high-speed data bandwidth on network

Table - CDC Subclasses

CDC Architecture

Figure - General Architecture between a Host and Micrium’s CDC Class in the *CDC Architecture* page shows the general architecture between the host and the device using CDC available from Micriµm.

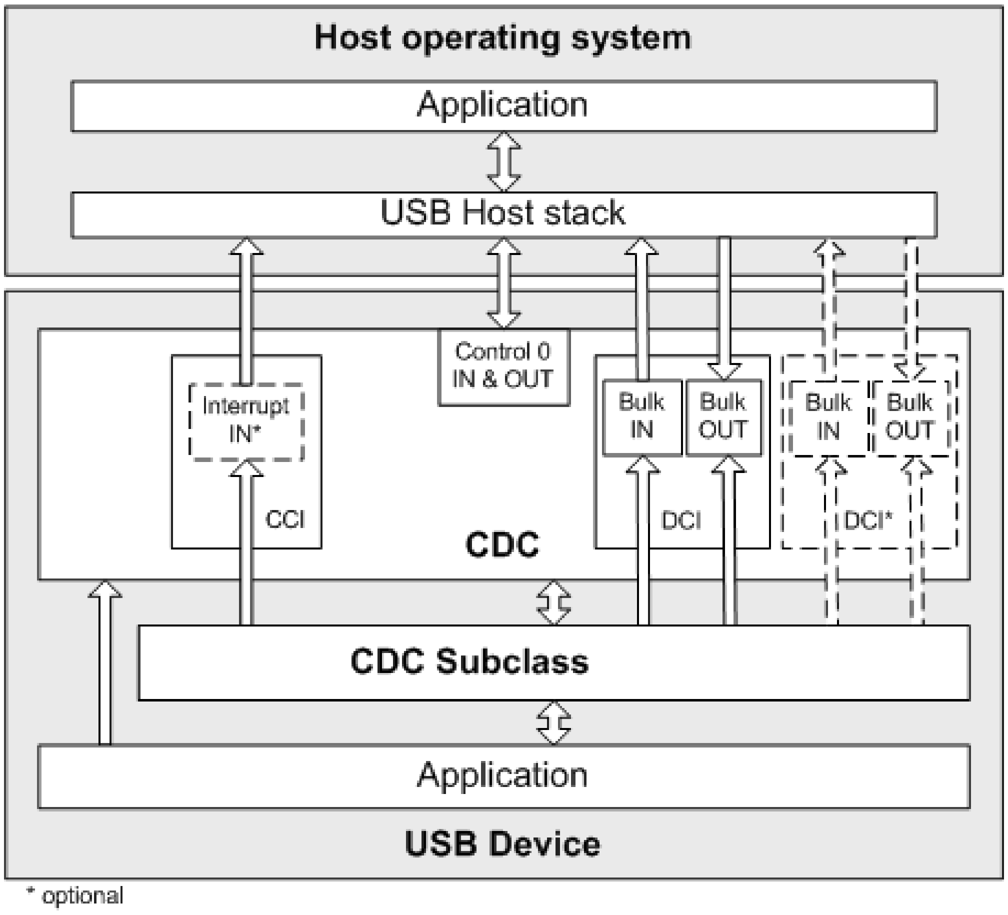


Figure - General Architecture between a Host and Micriµm's CDC Class

The host operating system (OS) enumerates the device using the control endpoints. Once the enumeration phase is done, the host can configure the device by sending class-specific requests to the Communications Class Interface (CCI) via the control endpoints. The class-specific requests vary according to the CDC subclasses. Micrium’s CDC base class offers the possibility to allocate an interrupt endpoint for event notification, depending on the subclass needs.

Following enumeration and configuration of the device, the host can start the transmission/reception of data to/from the device using the bulk endpoints belonging to the Data Class Interface (DCI). Isochronous endpoints are not supported in the current implementation. The CDC base class enables you to have several DCIs along with the CCI. The application can communicate with the host using the communication API offered by the CDC subclass.

As a CDC function is described by a minimum of two interfaces, when the CDC function is used with other class functions to form a composite device, the Interface Association Descriptor (IAD) must be present in the Configuration descriptor. IAD groups two or more interfaces so that the host sees these interfaces as one unique class function. It allows the host to load the same driver for all these interfaces to manage the CDC function. As soon as the CDC class is added to a configuration during the class initialization, the µC/USB-Device stack automatically configures the use of IAD for this CDC function. Thus, IAD will be always part of the Configuration descriptor whatever the device type, single or composite.

IAD is supported under Mac OS X 10.7 and later. Prior versions of Mac OS X do not support IADs, and moreover can only support non-composite, single function CDC devices. Nevertheless given that USB device stack always uses IAD, a single CDC device won't work with Mac OS X prior to version 10.7.

CDC Configuration

Some constants are available to customize the CDC base class. These constants are located in the USB device configuration file, `usbd_cfg.h`. Table - CDC Class Configuration Constants in the *CDC Configuration* page shows their description.

Constant	Description	Possible Values
`USBD_CDC_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances. Each associated subclass also defines a maximum number of subclass instances. The sum of all the maximum numbers of subclass instances must *not* be greater than `USBD_CDC_CFG_MAX_NBR_DEV`.	From 1 to 254. Default value is **1**.
`USBD_CDC_CFG_MAX_NBR_CFG`	Configures the maximum number of configurations in which CDC class is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed.	From 1 (low- and full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_CDC_CFG_MAX_NBR_DATA_IF`	Configures the maximum number of Data interfaces.	From 1 to 254. The default value is **1**.

Table - CDC Class Configuration Constants

Listing - CDC Initialization Example in the *CDC Configuration* page shows the `App_USBD_CDC_Init()` function defined in the application template file `app_usbd_cdc.c`. This function performs CDC and associated subclass initialization.

```
CPU_BOOLEAN  App_USBD_CDC_Init (CPU_INT08U  dev_nbr,
                                CPU_INT08U  cfg_hs,
                                CPU_INT08U  cfg_fs)
{
    USBD_ERR  err;


    USBD_CDC_Init(&err);                                                    (1)

    ...                                                                     (2)
}
```

Listing - CDC Initialization Example

(1) Initialize CDC internal structures and variables. This is the first function you should call and you should do it only once.

(2) Call all the required functions to initialize the subclass(es). Refer to the ACM Subclass

Configuration section for ACM subclass initialization.

ACM Subclass

The ACM subclass is used by two types of communication devices:

- Devices supporting AT commands (for instance, voiceband modems).
- Serial emulation devices which are also called Virtual COM port devices.

Micrium’s ACM subclass implementation complies with the following specification:

- *Universal Serial Bus, Communications, Subclass for PSTN Devices, revision 1.2, February 9, 2007*.

Overview

The general characteristics of the CDC base class in terms of Communications Class Interface (CCI) and Data Class Interface (DCI) were presented in the CDC Class Overview page. In this section, a CCI of type ACM is considered. It will consist of a default endpoint for the management element and an interrupt endpoint for the notification element. A pair of bulk endpoints is used to carry unspecified data over the DCI.

Several subclass-specific requests exists for the ACM subclass. They allow you to control and configure the device. The complete list and description of all ACM requests can be found in the specification “*Universal Serial Bus, Communications, Subclass for PSTN Devices, revision 1.2, February 9, 2007*”, section 6.2.2. From this list, Micrium’s ACM subclass supports:

Subclass request	Description
`SetCommFeature`	The host sends this request to control the settings for a particular communications feature. Not used for serial emulation.
`GetCommFeature`	The host sends this request to get the current settings for a particular communications feature. Not used for serial emulation.
`ClearCommFeature`	The host sends this request to clear the settings for a particular communications feature. Not used for serial emulation.
`SetLineCoding`	The host sends this request to configure the ACM device settings in terms of baud rate, number of stop bits, parity type and number of data bits. For a serial emulation, this request is sent automatically by a serial terminal each time you configure the serial settings for an open virtual COM port.
`GetLineCoding`	The host sends this request to get the current ACM settings (baud rate, stop bits, parity, data bits). For a serial emulation, serial terminals send this request automatically during virtual COM port opening.
`SetControlLineState`	The host sends this request to control the carrier for half duplex modems and indicate that Data Terminal Equipment (DTE) is ready or not. In the serial emulation case, the DTE is a serial terminal. For a serial emulation, certain serial terminals allow you to send this request with the controls set.
`SetBreak`	The host sends this request to generate an RS-232 style break. For a serial emulation, certain serial terminals allow you to send this request.

Table - ACM Requests Supported by Micrium

Micrium's ACM subclass uses the interrupt IN endpoint to notify the host about the current *serial line state*. The serial line state is a bitmap informing the host about:

- Data discarded because of overrun
- Parity error
- Framing error
- State of the ring signal detection
- State of break detection mechanism
- State of transmission carrier
- State of receiver carrier detection

Configuration

Table - ACM Serial Emulation Subclass Configuration Constants in the *ACM Subclass* page shows the constant available to customize the ACM serial emulation subclass. This constant is located in the USB device configuration file, `usbd_cfg.h`.

Constant	Description	Possible Values
`USBD_ACM_SERIAL_CFG_MAX_NBR_DEV`	Configures the maximum number of subclass instances. The constant value cannot be greater than `USBD_CDC_CFG_MAX_NBR_DEV`. Unless you plan on having multiple configurations or interfaces using different class instances, this can be set to the default value.	From 1 to `USBD_CDC_CFG_MAX_NBR_DEV`. Default value is **1**.

Table - ACM Serial Emulation Subclass Configuration Constants

Subclass Instance Configuration

Before starting the communication phase, your application needs to initialize and configure the class to suit its needs. Table - ACM Subclass Initialization API Summary in the *ACM Subclass* page summarizes the initialization functions provided by the ACM subclass. For more details about the functions' parameters, refer to the CDC ACM Subclass Functions reference.

Function name	Operation
`USBD_ACM_SerialInit()`	Initializes ACM subclass internal structures and variables.
`USBD_ACM_SerialAdd()`	Creates a new instance of ACM subclass.
`USBD_ACM_SerialCfgAdd()`	Adds an existing ACM instance to the specified device configuration.
`USBD_ACM_SerialLineCodingReg()`	Registers line coding notification callback.
`USBD_ACM_SerialLineCtrlReg()`	Registers line control notification callback.

Table - ACM Subclass Initialization API Summary

You need to call these functions in the order shown below to successfully initialize the ACM subclass:

1. Call `USBD_ACM_SerialInit()`
   This function initializes all internal structures and variables that the ACM subclass needs. You should call this function only once even if you use multiple class instances.

2. Call `USBD_ACM_SerialAdd()`
   This function allocates an ACM subclass instance. Internally, this function allocates a CDC class instance. It also allows you to specify the line state notification interval expressed in milliseconds and the Call Management capabilities.

3. Call `USBD_ACM_SerialLineCodingReg()`
   This function allows you to register a callback used by the ACM subclass to notify the application about a change in the serial line coding settings (that is baud rate, number of stop bits, parity and number of data bits).

4. Call `USBD_ACM_SerialLineCtrlReg()`
   This function allows you to register a callback used by the ACM subclass to notify the application about a change in the serial line state (that is RS-232 break signal, carrier control, i.e. RS-232 RTS signal, and a flag indicating that data equipment terminal is present or not, i.e. RS-232 DTR signal,).

5. Call `USBD_ACM_SerialCfgAdd()`
   Finally, once the ACM subclass instance has been created, you must add it to a specific configuration.

Listing - CDC ACM Subclass Initialization Example in the *ACM Subclass* page illustrates the use of the previous functions for initializing the ACM subclass. Note that the error handling has been omitted for clarity.

```
CPU_BOOLEAN  App_USBD_CDC_Init (CPU_INT08U  dev_nbr,
                                CPU_INT08U  cfg_hs,
                                CPU_INT08U  cfg_fs)
{
    USBD_ERR    err;
    CPU_INT08U  subclass_nbr;


    USBD_CDC_Init(&err);                                                    (1)

    USBD_ACM_SerialInit(&err);                                              (2)
                                                                            (3)
    subclass_nbr = USBD_ACM_SerialAdd(64u,
                                     (USBD_ACM_SERIAL_CALL_MGMT_DATA_CCI_DCI |
USBD_ACM_SERIAL_CALL_MGMT_DEV),
                                     &err);

    USBD_ACM_SerialLineCodingReg(        subclass_nbr,                      (4)
                                         App_USBD_CDC_SerialLineCoding,
                                 (void *)0,
                                        &err);

    USBD_ACM_SerialLineCtrlReg(        subclass_nbr,                        (5)
                                       App_USBD_CDC_SerialLineCtrl,
                               (void *)0,
                                      &err);

    if (cfg_hs != USBD_CFG_NBR_NONE) {
        USBD_ACM_SerialCfgAdd(subclass_nbr, dev_nbr, cfg_hs, &err);         (6)
    }

    if (cfg_fs != USBD_CFG_NBR_NONE) {
        USBD_ACM_SerialCfgAdd(subclass_nbr, dev_nbr, cfg_fs, &err);         (7)
    }
}
```

Listing - CDC ACM Subclass Initialization Example

(1) Initialize CDC internal structures and variables.

(2) Initialize CDC ACM internal structures and variables.

(3) Create a new CDC ACM subclass instance. In this example, the line state notification interval is 64 ms. In the CCI, an interrupt IN endpoint is used to asynchronously notify the host of the status of the different signals forming the serial line. The line state notification interval corresponds to the interrupt endpoint's polling interval. The second argument allows to specify the Call Management support of the CDC ACM function. In this example, the device handles the call management itself (`USBD_ACM_SERIAL_CALL_MGMT_DEV`) and information can be set over a DCI (`USBD_ACM_SERIAL_CALL_MGMT_DATA_CCI_DCI`).

Mac OS X supports only all combinations of the call management capabilities except: (`USBD_ACM_SERIAL_CALL_MGMT_DEV`). For this latter combination, Mac OS X won't recognize the CDC ACM function. Windows and Linux operating systems accept any combinations of the flags. See `USBD_ACM_SerialAdd()` for more details about the possible flags combinations.

(4) Register the application callback, `App_USBD_CDC_SerialLineCoding()`. It is called by the ACM subclass when the class-specific request `SET_LINE_CODING` has been received by the device. This request allows the host to specify the serial line settings (baud rate, stop bits, parity and data bits). Refer to "*CDC PSTN Subclass, revision 1.2*", section 6.3.10 for more details about this class-specific request.

(5) Register the application callback, `App_USBD_CDC_SerialLineCtrl()`. It is called by the ACM subclass when the class-specific request `SET_CONTROL_LINE_STATE` has been received by the device. This request generates RS-232/V.24 style control signals. Refer to "*CDC PSTN Subclass, revision 1.2*", section 6.3.12 for more details about this class-specific request.

(6) Check if the high-speed configuration is active and proceed to add the ACM subclass instance to this configuration.

(7) Check if the full-speed configuration is active and proceed to add the ACM subclass instance to this configuration.

Listing - CDC ACM Subclass Initialization Example in the *ACM Subclass* page also illustrates an example of multiple configurations. The functions `USBD_ACM_SerialAdd()` and `USBD_ACM_SerialCfgAdd()` allow you to create multiple configurations and multiple instances architecture. Refer to the Class Instance Concept page for more details about multiple class instances.

Subclass Notification and Management

You have access to some functions provides in the ACM subclass which relate to the ACM requests and the serial line state previously presented in the Overview section. Table - ACM Subclass Functions Related to the Subclass Requests and Notifications in the *ACM Subclass* page shows these functions. Refer to the CDC ACM Subclass Functions reference for more details about the functions' parameters.

Function	Relates to...	Description
`USBD_ACM_SerialLineCodingGet()`	`SetLineCoding`	Application can get the current line coding settings set either by the host with SetLineCoding requests or by `USBD_ACM_SerialLineCodingSet()`
`USBD_ACM_SerialLineCodingSet()`	`GetLineCoding`	Application can set the line coding. The host can retrieve the settings with the `GetLineCoding` request.
`USBD_ACM_SerialLineCodingReg()`	`SetLineCoding`	Application registers a callback called by the ACM subclass upon reception of the `SetLineCoding` request. Application can perform any specific operations.
`USBD_ACM_SerialLineCtrlGet()`	`SetControlLineState`	Application can get the current control line state set by the host with the `SetControlLineState` request.
`USBD_ACM_SerialLineCtrlReg()`	`SendBreak` `SetControlLineState`	Application registers a callback called by the ACM subclass upon reception of the `SendBreak` or `SetControlLineState` requests. Application can perform any specific operations.
`USBD_ACM_SerialLineStateSet()`	Serial line state	Application can set any line state event(s). While setting the line state, an interrupt IN transfer is sent to the host to inform about it a change in the serial line state.
`USBD_ACM_SerialLineStateClr()`	Serial line state	Application can clear two events of the line state: transmission carrier and receiver carrier detection. All the other events are self-cleared by the ACM serial emulation subclass.

Table - ACM Subclass Functions Related to the Subclass Requests and Notifications

Micrium’s ACM subclass always uses the interrupt endpoint to notify the host of the serial line state. You cannot disable the interrupt endpoint.

Subclass Instance Communication

Micrium’s ACM subclass offers the following functions to communicate with the host. For more details about the functions’ parameters, refer to the CDC ACM Subclass Functions reference.

Function name	Operation
`USBD_ACM_SerialRx()`	Receives data from host through a bulk OUT endpoint. This function is blocking.
`USBD_ACM_SerialTx()`	Sends data to host through a bulk IN endpoint. This function is blocking.

Table - CDC ACM Communication API Summary

`USBD_ACM_SerialRx()` and `USBD_ACM_SerialTx()` provide synchronous communication which means that the transfer is blocking. Upon calling the function, the application blocks until transfer completion with or without an error. A timeout can be specified to avoid waiting forever. Listing - Serial Read and Write Example in the *ACM Subclass* page presents a read and write example to receive data from the host using the bulk OUT endpoint and to send data to the host using the bulk IN endpoint.

```
CPU_INT08U  rx_buf[2];
CPU_INT08U  tx_buf[2];
USBD_ERR    err;


(void)USBD_ACM_SerialRx(subclass_nbr,                                         (1)
                       &rx_buf[0],                                            (2)
                        2u,
                        0u,                                                   (3)
                       &err);
if (err != USBD_ERR_NONE) {
    /* Handle the error. */
}

(void)USBD_ACM_SerialTx(subclass_nbr,                                         (1)
                       &tx_buf[0],                                            (4)
                        2u,
                        0u,                                                   (3)
                       &err);
if (err != USBD_ERR_NONE) {
    /* Handle the error. */
}
```

Listing - Serial Read and Write Example

(1) The class instance number created with `USBD_ACM_SerialAdd()` will serve internally to the ACM subclass to route the transfer to the proper bulk OUT or IN endpoint.

(2) The application must ensure that the buffer provided to the function is large enough to accommodate all the data. Otherwise, synchronization issues might happen.

(3) In order to avoid an infinite blocking situation, a timeout expressed in milliseconds can be specified. A value of '0' makes the application task wait forever.

(4) The application provides the initialized transmit buffer.

Using the ACM Subclass Demo Application

Micrium provides a demo application that lets you test and evaluate the class implementation. Source template files are provided.

Note that the demo application provided by Micrium is only an example and is intended to be used as a starting point to develop your own application.

Configuring Device Application

The *serial* demo allows you to send and/or receive serial data to and/or from the device through a virtual COM port. The demo is implemented in the application file, `app_usbd_cdc.c`, provided for µC/OS-II and µC/OS-III. `app_usbd_cdc.c` is located in this folder:

- `\Micrium\Software\uC-USB-Device-V4\App\Device\`

Table - Device Application Configuration Constants in the *Using the ACM Subclass Demo Application* page describes the constants usually defined in `app_cfg.h` or `app_usbd_cfg.h` which allows you to use the serial demo.

Constant	Description	File
`APP_CFG_USBD_CDC_EN`	General constant to enable the CDC ACM demo application. Must be set to `DEF_ENABLED`.	`app_usbd_cfg.h`
`APP_CFG_USBD_CDC_SERIAL_TEST_EN`	Constant to enable the serial demo. Must be set to `DEF_ENABLED`.	`app_usbd_cfg.h`
`APP_CFG_USBD_CDC_SERIAL_TASK_PRIO`	Priority of the task used by the serial demo.	`app_cfg.h`
`APP_CFG_USBD_CDC_SERIAL_TASK_STK_SIZE`	Stack size of the task used by the serial demo. A default value can be 256.	`app_cfg.h`

Table - Device Application Configuration Constants

Running the Demo Application

In this section, we will assume Windows as the host operating system. Upon connection of your CDC ACM device, Windows will enumerate your device and load the native driver `usbser.sys` to handle the device communication. The first time you connect your device to the host, you will have to indicate to Windows which driver to load using an INF file (refer to the About INF Files page for more details about INF). The INF file tells Windows to load the `usbser.sys` driver. Indicating the INF file to Windows has to be done only once. Windows will then automatically recognize the CDC ACM device and load the proper driver for any new connection. The process of indicating the INF file may vary according to the Windows operating system version:

- Windows XP directly opens the Found New Hardware Wizard. Follow the different steps of the wizard until you reach the page where you can indicate the path of the INF file.

- Windows Vista and later won’t open a “Found New Hardware Wizard”. It will just indicate that no driver was found for the vendor device. You have to manually open the wizard. When you open the Device Manager, your CDC ACM device should appear with a yellow icon. Right-click on your device and choose ‘Update Driver Software...’ to open the wizard. Follow the different steps of the wizard until the page where you can indicate the path of the INF file.

The INF file is located in:

```
\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\CDC\INF
```

Refer to the About INF Files page for more details about how to edit the INF file to match your Vendor ID (VID) and Product ID (PID). The provided INF files define, by default, `0xFFFE` for VID and `0x1234` for PID. Once the driver is loaded, Windows creates a virtual COM port as shown in Figure - Windows Device Manager and Created Virtual COM Port in the *Using the ACM Subclass Demo Application* page.

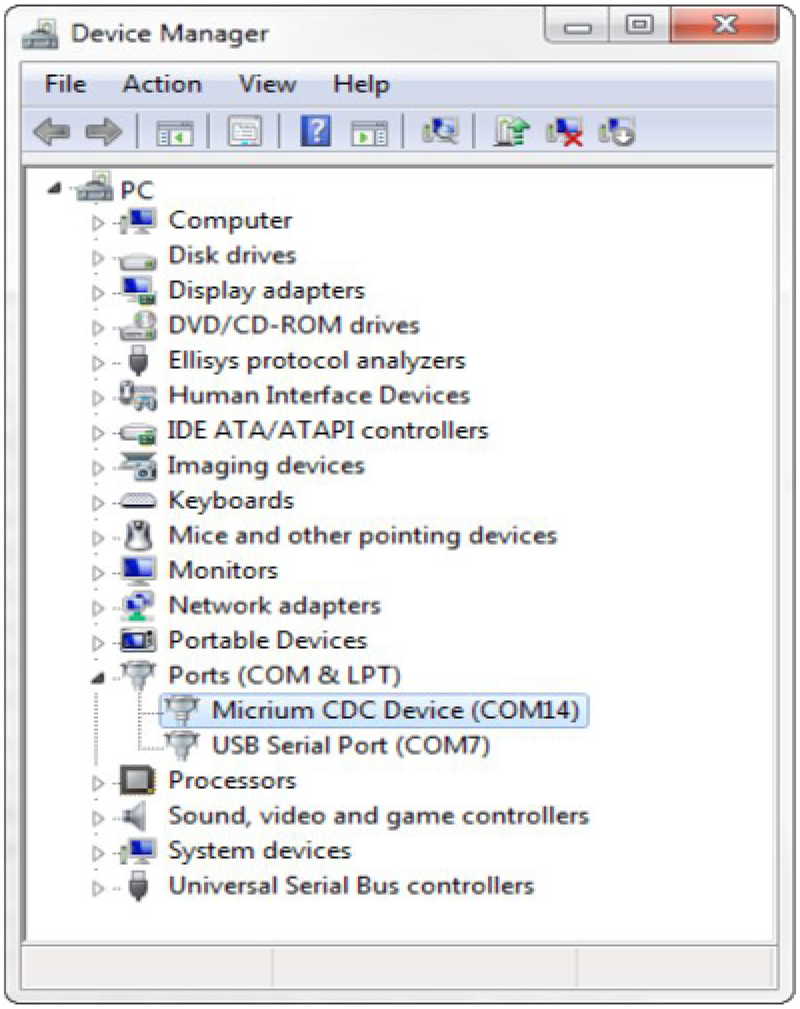


Figure - Windows Device Manager and Created Virtual COM Port

CDC ACM INF File Issue under Windows 8 and Later

`usbser.sys` driver is already digitally signed by Windows. Micriµm provides only an INF file, `usbser.inf`, telling Windows that your device uses that driver. Under Windows 7, providing this INF file was sufficient to load the driver `usbser.sys` for managing the CDC device. Windows 7 would display a warning message saying that the publisher of the driver can’t be verified but it was possible to continue the driver loading. Since Windows 8.x, Microsoft has enforced by default the loading of digitally signed driver packages. This is call the Driver Signature Enforcement. Windows 8.x won’t let you load the CDC driver if the driver package is not fully signed. The Micriµm CDC driver package is composed of `usbser.inf` (unsigned) and `usbser.sys` (signed). Basically, Windows 8.x requires a digitally signed INF file.

For development purposes, it is possible to disable the Driver Signature Enforcement. You can follow the instructions described on this page and you will be able to load the CDC driver and communicate with your USB device.

For your USB product release, you will have to follow the official procedure from Microsoft to sign the driver package (INF file + `usbser.sys`). The procedure is called the *Release-Signing* and is described here.
Micriµm cannot provide an already signed CDC driver package that would avoid disabling the Driver Signature Enforcement feature because the INF file contains a Vendor and Product IDs specific to the USB device manufacturer. For your USB product, the INF file must contain an official Vendor ID assigned to your company by the USB Implementer Forum. Micriµm does not possess an official USB vendor ID. It is the customer's responsibility to go through the official signing process as you are the USB device manufacturer.

Figure - Serial Demo in the *Using the ACM Subclass Demo Application* page presents the steps to follow to use the serial demo.

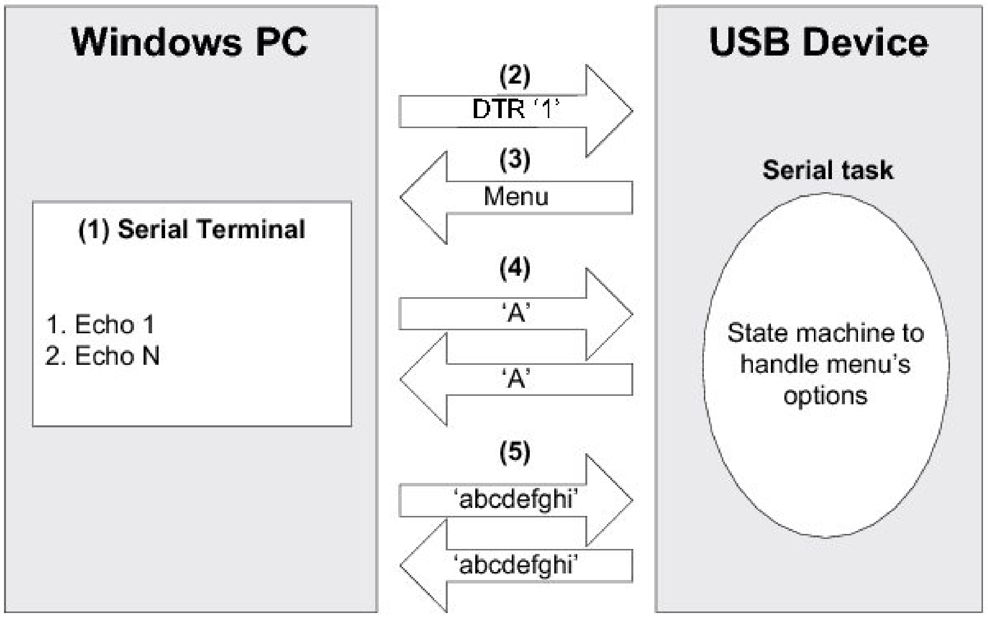


Figure - Serial Demo

(1) Open a serial terminal (for instance, HyperTerminal). Open the COM port matching to your CDC ACM device with the serial settings (baud rate, stop bits, parity and data bits) you want. This operation will send a series of CDC ACM class-specific requests (`GET_LINE_CODING`, `SET_LINE_CODING`, `SET_CONTROL_LINE_STATE`) to your device. Note that Windows Vista and later don't provide HyperTerminal anymore. You may use other free

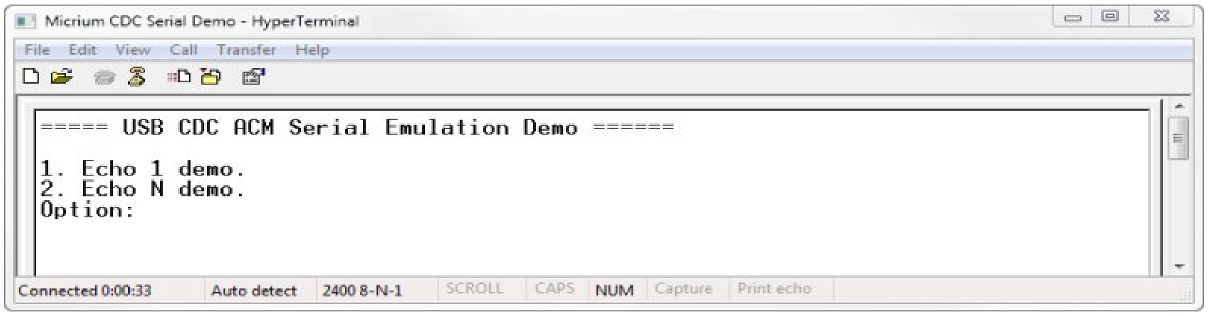
serial terminals such *TeraTerm* (`http://ttssh2.sourceforge.jp/`), *Hercules* (`http://www.hw-group.com/products/hercules/index_en.html`), *RealTerm* (`http://realterm.sourceforge.net/`), etc.

(2) In order to start the communication with the serial task on the device side, the Data Terminal Ready (DTR) signal must be set and sent to the device. The DTR signal prevents the serial task from sending characters if the terminal is not ready to receive data. Sending the DTR signal may vary depending on your serial terminal. For example, *HyperTerminal* sends a properly set DTR signal automatically upon opening of the COM port. *Hercules* terminal allows you to set and clear the DTR signal from the graphical user interface (GUI) with a checkbox. Other terminals do not permit to set/clear DTR or the DTR set/clear's functionality is difficult to find and to use.

(3) Once the serial task receives the DTR signal, the task sends a menu to the serial terminal with two options as presented in Figure - CDC Serial Demo Menu in HyperTerminal in the *Using the ACM Subclass Demo Application* page.

(4) The menu option #1 is the *Echo 1 demo*. It allows you to send one unique character to the device. This character is received by the serial task and sent back to the host.

(5) The menu options #2 is the *Echo N demo.* It allows you to send several characters to the device. All the characters are received by the serial task and sent back to the host. The serial task can receive a maximum of 512 characters.


Micrium CDC Serial Demo - HyperTerminal
File Edit View Call Transfer Help
Connected 0:00:33
Auto detect
2400 8-N-1
SCROLL
CAPS
NUM
Capture
Print echo

```
===== USB CDC ACM Serial Emulation Demo ======

1. Echo 1 demo.
2. Echo N demo.
Option:
```

Figure - CDC Serial Demo Menu in HyperTerminal

To support the two demos, the serial task implements a state machine as shown in Figure - Serial Demo State Machine in the *Using the ACM Subclass Demo Application* page. Basically, the state machine has two paths corresponding to the user choice in the serial terminal menu.

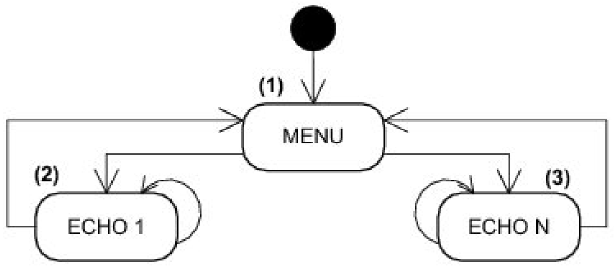


Figure - Serial Demo State Machine

(1) Once the DTR signal has been received, the serial task is in the MENU state.

(2) If you choose the menu option #1, the serial task will echo back any single character sent by the serial terminal as long as "Ctrl+C" is not pressed.

(3) If you choose the menu option #2, the serial task will echo all the received characters sent by the serial terminal as long as "Ctrl+C" is not pressed.

Table - Serial Terminals and CDC Serial Demo in the *Using the ACM Subclass Demo Application* page shows four possible serial terminals which you may use to test the CDC ACM class.

Terminal	**DTR set/clear**	**Menu option(s) usable**
HyperTerminal	Yes (properly set DTR signal automatically sent upon COM port opening)	1 and 2
Hercules	Yes (a checkbox in the GUI allows you to set/clear DTR)	1 and 2
RealTerm	Yes (Set/Clear DTR buttons in the GUI)	1 and 2
TeraTerm	Yes (DTR can be set using a macro. GUI does NOT allows you to set/clear DTR easily)	1 and 2

Table - Serial Terminals and CDC Serial Demo

CDC Ethernet Emulation Model Subclass

This section describes the Communication Device Class Ethernet Emulation Model subclass (CDC EEM) supported by C/USB-Device. The CDC EEM implementation offered by C/USB-Device is in compliance with the following specification:

- *Universal Serial Bus Communications Class Subclass Specification for Ethernet Emulation Model Devices*, Revision 1.0 February 2, 2005.

CDC EEM is a protocol that allows the usage of the USB as an Ethernet link. The device is seen by the host as a device on an Ethernet network. Hence, all typical applications can be run on the device (FTP, HTTP, DHCP, etc.).

Microsoft Windows and Apple Mac OS do not provide any driver for CDC EEM devices. However, commercial drivers can easily be found. Linux supports CDC EEM devices since kernel version 2.6.34.

CDC EEM represents the physical layer in the OSI model. It requires a network stack to implement higher layers. µC/TCP-IP offers an Ethernet driver for µC/USB-Device's CDC EEM subclass.

CDC EEM Subclass Overview

Overview

A CDC EEM device is composed of the following endpoints:

- A pair of Bulk IN and OUT endpoints.

Table - CDC EEM Subclass Endpoints Usage in the *CDC EEM Subclass Overview* page describes the usage of the different endpoints:

Endpoint	Direction	Usage
Bulk In	Device-to-host	Send Ethernet frames and commands to host.
Bulk OUT	Host-to-device	Receive Ethernet frames and commands from host.

Table - CDC EEM Subclass Endpoints Usage

CDC EEM Messages

CDC EEM defines a header that is prepended to each message sent to / received from the host. The CDC EEM header has a size of two bytes. A USB transfer on the Bulk endpoints can contain multiple EEM messages. An EEM message can also span on multiple USB transfers.

Table - CDC EEM Message Format in the *CDC EEM Subclass Overview* page describes the content of a CDC EEM message.

Bytes	0..1	2..N
Content	Header	Payload (optional)

Table - CDC EEM Message Format

Table - CDC EEM Header Format in the *CDC EEM Subclass Overview* page describes the content of a CDC EEM header.

Bit	15	14 .. 0
Content	bmType	Depends on bmType value

Table - CDC EEM Header Format

- bmType represents the message type, either a regular Ethernet frame or a CDC EEM specific command.

Table - CDC EEM Data Header Format in the *CDC EEM Subclass Overview* page describes the content of a CDC EEM data message header.

Bit	15	14	13 .. 0
Content	bmType (0)	bmCRC	Length of Ethernet frame

Table - CDC EEM Data Header Format

- bmCRC indicates if the CRC was calculated on the Ethernet frame. If not, CRC is set to 0xDEADBEEF.

Table - CDC EEM Command Header Format in the *CDC EEM Subclass Overview* page describes the content of a CDC EEM command message header. Note that the EEM commands provide USB local link management. This management is opaque to the network stack.

Bit	15	14	13 .. 11	10 .. 0
Content	bmType (1)	bmReserved (0)	bmEEMCmd	bmEEMCmdParam

Table - CDC EEM Command Header Format

- bmEEMCmd represents the command code to execute.
- bmEEMCmdParam contains command data. Fomat depends on the bmEEMCmd.

For more information on CDC EEM messages format, see "Universal Serial Bus Communications Class Subclass Specification for Ethernet Emulation Model Devices" revision 1.0. February 2, 2005, section 5.1.

CDC EEM Subclass Architecture

Overview

CDC EEM represents the "glue" between the USB domain and the Ethernet domain. The USB device stack along with the CDC EEM subclass is seen as the physical layer by the network stack. A simple driver is needed to interface the network stack to the CDC EEM subclass. Figure - CDC EEM Architecture and Interactions in the *CDC EEM Subclass Architecture* page shows the architecture and interactions of a network device using the CDC EEM subclass.

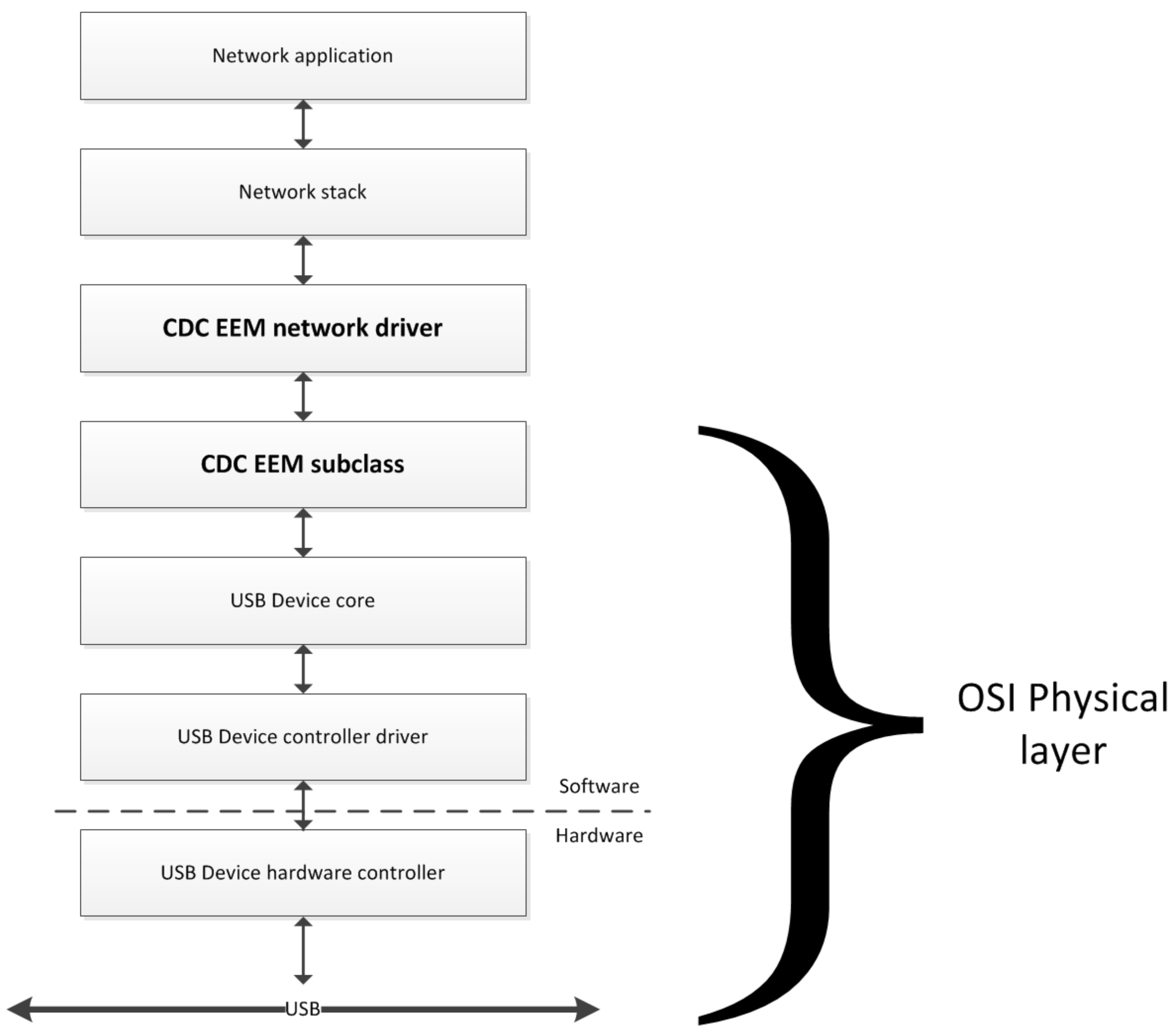


Figure - CDC EEM Architecture and Interactions

Buffer management

The CDC EEM subclass implementation offers a queuing mechanism for receive and transmit buffers.

Transmit buffers

The CDC EEM subclass allows the network driver to submit multiple transmit buffers. Once submitted by the network driver, a EEM header will be prepended in the first two bytes of the buffer. The CDC EEM subclass will then submit them through the Bulk IN endpoint in a First In First Out (FIFO) order. Once the transmission over the Bulk IN endpoint is completed, the buffer will be freed back to the network driver.

Receive buffers

The CDC EEM subclass will submit 1 to N buffers to the Bulk OUT endpoint in order to always be able to receive packets from the host. Using only one USB receive buffer will be enough, however not always optimal.

The number of buffers submitted to the USB device core can be configured. See CDC EEM Subclass Configuration for more information about how to configure the number of USB receive buffers.

Once an EEM message is received, the header is parsed. If it contains an Ethernet frame, a receive buffer is requested from the network driver. The content of the Ethernet frame is copied and the buffer is placed in the receive queue. Finally, the network driver is notified of the availability of a receive buffer and it will get it when possible. Note that if no receive buffer is available from the network stack at the moment of the reception, the packet will be lost.

The USB EEM receive buffers should NOT be confused with the receive buffers from the network stack. Having only one USB receive buffer is normally safe and appropriate for most of the applications. However, the number of network receive buffers should normally be larger as network stacks are likely to hold the buffers for a longer period of time before marking them as free.

CDC EEM Subclass Configuration

General Configuration

There are various configuration constants necessary to customize the CDC EEM subclass. These constants are located in the `usbd_cfg`.h file. Table - CDC EEM Configuration Constants in the *CDC EEM Subclass Configuration* page shows a description of each constant.

Constant	Description	Possible Values
`USBD_CDC_EEM_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances. Unless you plan having multiple configuration or interfaces using different class instances, this should be set to **1**.	From 1 to 254. Default value is **1** .
`USBD_CDC_EEM_CFG_MAX_NBR_CFG`	Configures the maximum number of configuration in which CDC EEM is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed.	From 1 (full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_CDC_EEM_CFG_RX_BUF_LEN`	Configures the length, in octets, of the buffer(s) used to receive the data from the host. This buffer must ideally be a multiple of the max packet size of the endpoint. However, most of the time this can be set to the Ethernet Maximum Transmit Unit (MTU -> 1518) + 2 for the CDC EEM header for better performances.	64 or more. Multiple of maximum packet size if below (MTU + 2). Default value is **1520**.
`USBD_CDC_EEM_CFG_ECHO_BUF_LEN`	Configures the length, in octets, of the echo buffer used to transmit an echo response command upon reception of an echo command from the host. Size of this buffer depends on the largest possible echo data that can be sent by the host.	Higher than 2. Default value is **64.**
`USBD_CDC_EEM_CFG_RX_BUF_QTY_PER_DEV` **(optional)**	Configures the quantity of receive buffers to be used to receive data from the host. It is not mandatory to set the value in your `usbd_cfg.h` file. Before setting this value to something higher than 1, you MUST ensure that you USB device driver supports URB queuing. You must also correctly configure the constant `USBD_CFG_MAX_NBR_URB_EXTRA`. Increasing this value will improve the data reception performances by providing multiple buffering mechanism.	1 or more. Default value is **1** .

Table - CDC EEM Configuration Constants

Class Instance Configuration

Before starting the communication phase, your application needs to initialize and configure the class to suit its needs. Table - Class Instance Initialization API Functions in the *CDC EEM Subclass Configuration* page summarizes the initialization functions provided by the CDC EEM implementation. Please refer to the CDC EEM API reference for a full listing of the CDC EEM API.

Function name	Operation
`USBH_CDC_EEM_Init()`	Initializes CDC EEM internal structures and variables.
`USBH_CDC_EEM_Add()`	Adds a new instance of the CDC EEM subclass.
`USBD_CDC_EEM_CfgAdd()`	Adds existing CDC EEM instance into USB device configuration.

Table - Class Instance Initialization API Functions

To successfully initialize the CDC EEM subclass, you need to follow these steps:

1. Call `USBD_CDC_EEM_Init()`
   This is the first function you should call, and it should be called only once regardless of the number of class instances you intend to have. This function will initialize all internal structures and variables that the class will need.

2. Call `USBD_CDC_EEM_Add()`
   This function will add a new instance of the CDC EEM subclass.

3. Call `USBD_CDC_EEM_CfgAdd()`
   Once the class instance is correctly configured and initialized, you will need to add it to a USB configuration. High speed devices will build two separate configurations, one for full speed and one for high speed by calling `USBD_CDC_EEM_CfgAdd()` for each speed configuration.

4. Add a network interface using CDC EEM as the physical link.
   For more information on how to initialize the μC/TCP-IP stack, see UserManual.

Listing - CDC EEM Initialization Example in the *CDC EEM Subclass Configuration* page shows how the latter functions are called during CDC EEM initialization and an example of creation and initialization of a CDC EEM network interface using μC/TCP-IP.

```
USBD_ERR       err;
NET_IF_NBR     net_if_nbr;
NET_IPv4_ADDR  addr;
NET_IPv4_ADDR  subnet_mask;
NET_IPv4_ADDR  dflt_gateway;
NET_ERR        err_net;


USBD_CDC_EEM_Init(&err);                                    /* CDC EEM class initialization.
*/  (1)
if (err != USBD_ERR_NONE) {
    return (DEF_FAIL);
}

cdc_eem_nbr = USBD_CDC_EEM_Add(&err);                       /* Create CDC EEM class instance.
*/  (2)
if (err != USBD_ERR_NONE) {
    return (DEF_FAIL);
}

                                                            /* Add CDC EEM class instance to USB
configuration(s).  */  (3)
if (cfg_hs != USBD_CFG_NBR_NONE) {
    USBD_CDC_EEM_CfgAdd(cdc_eem_nbr,
                        dev_nbr,
                        cfg_hs,
                       "CDC EEM interface",
                       &err);
    if (err != USBD_ERR_NONE) {
        return (DEF_FAIL);
    }
}

if (cfg_fs != USBD_CFG_NBR_NONE) {
    USBD_CDC_EEM_CfgAdd(cdc_eem_nbr,
                        dev_nbr,
                        cfg_fs,
                       "CDC EEM interface",
                       &err);
    if (err != USBD_ERR_NONE) {
        return (DEF_FAIL);
    }
}
                                                            /* Add uC/TCP-IP interface using CDC EEM.
*/
NetDev_Cfg_Ether_USBD_CDCEEM.ClassNbr = cdc_eem_nbr;        /* Set CDC EEM class instance number to drv
cfg.        */   (4)
net_if_nbr = NetIF_Add((void *)&NetIF_API_Ether,
(5)
                       (void *)&NetDev_API_USBD_CDCEEM,
                                DEF_NULL,
                       (void *)&NetDev_Cfg_Ether_USBD_CDCEEM,
                                DEF_NULL,
                                DEF_NULL,
                               &err_net);
if (err_net != NET_IF_ERR_NONE) {
    return (DEF_FAIL);
}
                                                            /* Set static address to device.
*/   (6)
addr         = NetASCII_Str_to_IPv4("192.168.0.10",
                                    &err_net);
subnet_mask  = NetASCII_Str_to_IPv4("255.255.255.0",
                                    &err_net);
dflt_gateway = NetASCII_Str_to_IPv4("192.168.0.1",
                                    &err_net);
NetIPv4_CfgAddrAdd(net_if_nbr,
                   addr,
                   subnet_mask,
                   dflt_gateway,
                  &err_net);
if (err_net != NET_IPv4_ERR_NONE) {
    return (DEF_FAIL);
}

NetIF_Start(net_if_nbr, &err_net);                          /* Start uC/TCP-IP interface.
*/   (7)
if (err_net != NET_IF_ERR_NONE) {
    return (DEF_FAIL);
}
```

Listing - CDC EEM Initialization Example

(1) Initialize CDC EEM subclass.

(2) Create an instance of the CDC EEM subclass.

(3) Add CDC EEM subclass instance to USB configuration(s).

(4) Set CDC EEM class instance number in network driver configuration structure to be retrieved by µC/TCP-IP's USBD_CDCEEM driver.

(5) Add a new ethernet interface using USBD_CDCEEM driver.

(6) In this example, a static address is assigned to the device.

(7) Start the network interface.

Class Instance Configuration by Network Driver

The network driver that interfaces with the CDC EEM subclass must initialize the class instance with its specific requirements. This is done by calling the function `USBD_CDC_EEM_InstanceInit()` from the interface initialization function of the network driver. This function must be called only once. Listing - CDC EEM Instance init function in the *CDC EEM Subclass Configuration* page gives the prototype of the function `USBD_CDC_EEM_InstanceInit()`.

```
void  USBD_CDC_EEM_InstanceInit (CPU_INT08U         class_nbr,
                                 USBD_CDC_EEM_CFG  *p_cfg,              (1)
                                 USBD_CDC_EEM_DRV  *p_cdc_eem_drv,      (2)
                                 void              *p_arg,              (3)
                                 USBD_ERR          *p_err)
```

Listing - CDC EEM Instance init function

(1) Takes a pointer to a structure that contains the desired size of the receive and transmit buffers queue . Following listing gives the prototype of the configuration structure.

```
typedef  struct  usbd_cdc_eem_cfg {
    CPU_INT08U  RxBufQSize;                                     /* Size of rx buffer Q.
*/
    CPU_INT08U  TxBufQSize;                                     /* Size of tx buffer Q.
*/
} USBD_CDC_EEM_CFG;
```

(2) Takes a pointer to the CDC EEM driver. Following listing gives the details of the CDC EEM driver API.

```
typedef  const  struct  usbd_cdc_eem_drv {
                                                                /* Retrieve a Rx buffer.
*/
    CPU_INT08U  *(*RxBufGet)   (CPU_INT08U   class_nbr,
                                void        *p_arg,
                                CPU_INT16U  *p_buf_len);
                                                                /* Signal that a rx buffer is
ready.                     */
    void         (*RxBufRdy)   (CPU_INT08U   class_nbr,
                                void        *p_arg);
                                                                /* Free a tx buffer.
*/
    void         (*TxBufFree)  (CPU_INT08U   class_nbr,
                                void        *p_arg,
                                CPU_INT08U  *p_buf,
                                CPU_INT16U   buf_len);
} USBD_CDC_EEM_DRV;
```

(3) Pointer to network driver data.

Configuration of Network Driver

The network driver used to interact with the CDC EEM class MUST follow some guidelines for the configuration of its buffers.

- The size of the receive AND transmit buffers MUST be set to 1518 bytes or more (MTU including CRC).
- The alignment of transmit buffers MUST be a multiple of the alignment required by the USB controller.
- The transmit buffers MUST have an offset of two (2) bytes at the beginning. This is necessary as the CDC EEM subclass will prepend the header.

Listing - Network Driver Configuration Example in the *CDC EEM Subclass Configuration* page gives an example of configuration when the µC/TCP-IP's USBD_CDCEEM driver is used.

```
NET_DEV_CFG_USBD_CDC_EEM  NetDev_Cfg_Ether_USBD_CDCEEM = {
    NET_IF_MEM_TYPE_MAIN,           /* Desired receive  buffer memory pool type :
*/
                                    /*   NET_IF_MEM_TYPE_MAIN        buffers allocated from main memory
*/
                                    /*   NET_IF_MEM_TYPE_DEDICATED   buffers allocated from (device's)
dedicated memory */
    1518u,                          /* Desired size      of device's large receive  buffers (in octets).
*/
      10u,                          /* Desired number    of device's large receive  buffers.
*/
    sizeof(CPU_ALIGN),              /* Desired alignment of device's       receive  buffers (in octets).
*/
       0u,                          /* Desired offset from base receive  index, if needed   (in octets).
*/
    NET_IF_MEM_TYPE_MAIN,           /* Desired transmit buffer memory pool type :
*/
                                    /*   NET_IF_MEM_TYPE_MAIN        buffers allocated from main memory
*/
                                    /*   NET_IF_MEM_TYPE_DEDICATED   buffers allocated from (device's)
dedicated memory */
    1518u,                          /* Desired size      of device's large transmit buffers (in octets).
*/
       2u,                          /* Desired number    of device's large transmit buffers.
*/
      60u,                          /* Desired size      of device's small transmit buffers (in octets).
*/
       1u,                          /* Desired number    of device's small transmit buffers.
*/
    USBD_CFG_BUF_ALIGN_OCTETS,      /* Desired alignment of device's       transmit buffers (in octets).
*/
       2u,                          /* Desired offset from base transmit index, if needed   (in octets).
*/
      "00:AB:CD:EF:80:01",          /* HW address.
*/
       0u                           /* USBD CDC EEM class nbr. MUST be set at runtime after call to
USBD_CDC_EEM_Add(). */
};
```

Listing - Network Driver Configuration Example

CDC EEM Demo Application

The CDC EEM demo consists of two parts:

- A USB host that supports CDC EEM (Linux, for instance).
- The USB Device application on the target board which responds to the request of the host.

Note that the demo application provided by Micriµm is only an example and is intended to be used as a starting point to develop your own application.

CDC EEM Device Application

On the target side, the user configures the application through the `app_usbd_cfg.h` file. Table - CDC EEM Application Example Configuration Constants in the *CDC EEM Demo Application* page lists a few preprocessor constants that must be defined.

Preprocessor Constants	Description	Default Value
`APP_CFG_USBD_EN`	Enables µC/USB Device in the application.	`DEF_ENABLED`
`APP_CFG_USBD_CDC_EEM_EN`	Enables CDC EEM in the application.	`DEF_ENABLED`

Table - CDC EEM Application Example Configuration Constants

The CDC EEM application example only performs an initialization of the class and Ethernet interface using µC/TCP-IP. Once initialized, the application will let you do basic operations like ICMP echo requests (ping).

CDC EEM Host Application

As of now, only Linux operating system has built-in support for CDC EEM devices. Note that some third-party commercial drivers can be found for Microsoft Windows and Apple Mac OS.

Once connected to a Linux host, the operating system will add a new network interface called "usbx" (where x is a number starting from 0). The command `ifconfig` can be used from a terminal to see the different network interfaces available and to set a static IP address to the "usbx" interface, which will be necessary if you don't have a DHCP server on your target. Once done, you should be ready to perform `ping` commands form a terminal and use any other application implemented on your device (HTTP, FTP, etc).

Human Interface Device Class

This chapter describes the Human Interface Device (HID) class supported by C/USB-Device. The HID implementation complies with the following specifications:

- *Device Class Definition for Human Interface Devices (HID), 6/27/01, Version 1.11*.
- *Universal Serial Bus HID Usage Tables, 10/28/2004, Version 1.12.*

The HID class encompasses devices used by humans to control computer operations. Keyboards, mice, pointing devices, game devices are some examples of typical HID devices. The HID class can also be used in a composite device that contains some controls such as knobs, switches, buttons and sliders. For instance, mute and volume controls in an audio headset are controlled by the HID function of the headset. HID data can exchange data for any purpose using only control and interrupt transfers. The HID class is one of the oldest and most popular USB classes. All the major host operating systems provide a native driver to manage HID devices. That’s why a variety of vendor-specific devices work with the HID class. This class also includes various types of output directed to the user information (e.g. LEDs on a keyboard).

HID Class Overview

Overview

A HID device is composed of the following endpoints:

- A pair of control IN and OUT endpoints called the default endpoint.
- An interrupt IN endpoint.
- An optional interrupt OUT endpoint.

Table - HID Class Endpoints Usage in the *HID Class Overview* page describes the usage of the different endpoints:

Endpoint	Direction	Usage
Control IN	Device-to-host	Standard requests for enumeration, class-specific requests, and data communication (Input, Feature reports sent to the host with `GET_REPORT` request).
Control OUT	Host-to-device	Standard requests for enumeration, class-specific requests and data communication (Output, Feature reports received from the host with `SET_REPORT` request).
Interrupt IN	Device-to-host	Data communication (Input and Feature reports).
Interrupt OUT	Host-to-device	Data communication (Output and Feature reports).

Table - HID Class Endpoints Usage

Report

A host and a HID device exchange data using reports. A report contains formatted data giving information about controls and other physical entities of the HID device. A control is manipulable by the user and operates an aspect of the device. For instance, a control can be a button on a mouse or a keyboard, a switch, etc. Other entities inform the user about the state of certain device's features. For instance, LEDs on a keyboard notify the user about the caps lock on, the numeric keypad active, etc.

The format and the use of a report data is understood by the host by analyzing the content of a *Report descriptor*. Analyzing the content is done by a parser. The Report descriptor describes the data provided by each control in a device. It is composed of *items*. An item is a piece of information about the device and consists of a 1-byte prefix and variable-length data. Refer to "*Device Class Definition for Human Interface Devices (HID) Version 1.11*", section 5.6 and 6.2.2 for more details about the item format.

There are three principal types of items:

- *Main item* defines or groups certain types of data fields.
- *Global item* describes data characteristics of a control.
- *Local item* describes data characteristics of a control.

Each item type is defined by different functions. An item function can also be called a tag. An item function can be seen as a sub-item that belongs to one of the three principal item types. Table - Item's Function Description for each Item Type in the *HID Class Overview* page gives a brief overview of the item's functions in each item type. For a complete description of the items in each category, refer to "Device Class Definition for Human Interface Devices (HID) Version 1.11", section 6.2.2.

Item type	Item function	Description
Main	Input	Describes information about the data provided by one or more physical controls.
	Output	Describes data sent to the device.
	Feature	Describes device configuration information sent to or received from the device which influences the overall behavior of the device or one of its components.
	Collection	Group related items (Input, Output or Feature).
	End of Collection	Closes a collection.
Global	Usage Page	Identifies a function available within the device.
	Logical Minimum	Defines the lower limit of the reported values in logical units.
	Logical Maximum	Defines the upper limit of the reported values in logical units.
	Physical Minimum	Defines the lower limit of the reported values in physical units, that is the Logical Minimum expressed in physical units.
	Physical Maximum	Defines the upper limit of the reported values in physical units, that is the Logical Maximum expressed in physical units.
	Unit Exponent	Indicates the unit exponent in base 10. The exponent ranges from -8 to +7.
	Unit	Indicates the unit of the reported values. For instance, length, mass, temperature units, etc.
	Report Size	Indicates the size of the report fields in bits.
	Report ID	Indicates the prefix added to a particular report.
	Report Count	Indicates the number of data fields for an item.
	Push	Places a copy of the global item state table on the CPU stack.
	Pop	Replaces the item state table with the last structure from the stack.
Local	Usage	Represents an index to designate a specific Usage within a Usage Page. It indicates the vendor's suggested use for a specific control or group of controls. A usage supplies information to an application developer about what a control is actually measuring.
	Usage Minimum	Defines the starting usage associated with an array or bitmap.
	Usage Maximum	Defines the ending usage associated with an array or bitmap.
	Designator Index	Determines the body part used for a control. Index points to a designator in the Physical descriptor.
	Designator Minimum	Defines the index of the starting designator associated with an array or bitmap.
	Designator Maximum	Defines the index of the ending designator associated with an array or bitmap.
	String Index	String index for a String descriptor. It allows a string to be associated with a particular item or control.
	String Minimum	Specifies the first string index when assigning a group of sequential strings to controls in an array or bitmap.

	String Maximum	Specifies the last string index when assigning a group of sequential strings to controls in an array or bitmap.
	Delimiter	Defines the beginning or end of a set of local items.

Table - Item's Function Description for each Item Type

A control's data must define at least the following items:

- Input, Output or Feature Main items.
- Usage Local item.
- Usage Page Global item.
- Logical Minimum Global item.
- Logical Maximum Global item.
- Report Size Global item.
- Report Count Global item.

Table - HID Class Endpoints Usage in the *HID Class Overview* page shows the representation of a Mouse Report descriptor content from a host HID parser perspective. The mouse has three buttons (left, right and wheel). The code presented in Listing - Mouse Report Descriptor Example in the *HID Class Configuration* page is an example of code implementation corresponding to this mouse Report descriptor representation.

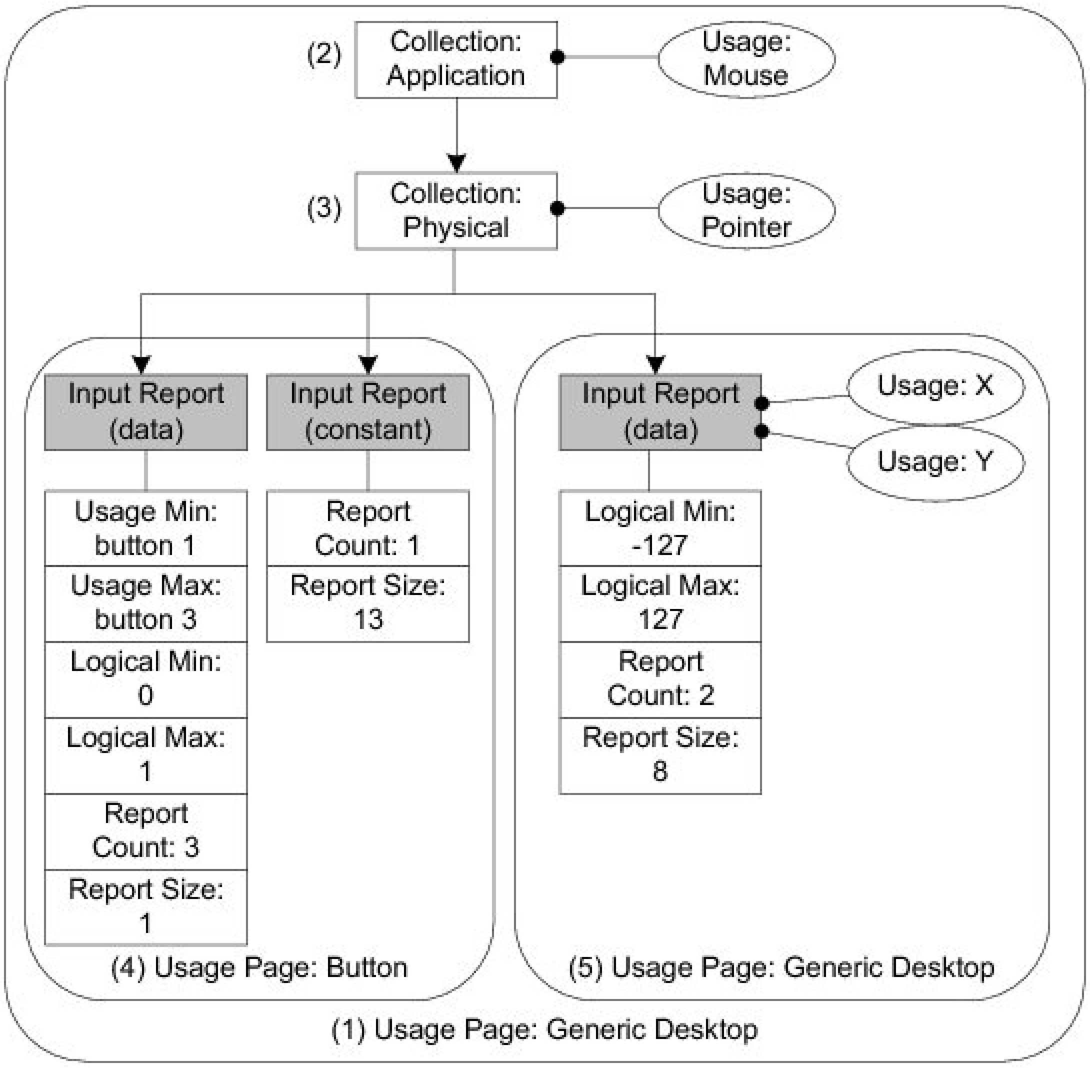


Figure - Report Descriptor Content from a Host HID Parser View

(1) The *Usage Page* item function specifies the general function of the device. In this example, the HID device belongs to a generic desktop control.

(2) The *Collection Application* groups Main items that have a common purpose and may be familiar to applications. In the diagram, the group is composed of three Input Main items. For this collection, the suggested use for the controls is a mouse as indicated by the *Usage* item.

(3) Nested collections may be used to give more details about the use of a single control or

group of controls to applications. In this example, the Collection Physical, nested into the Collection Application, is composed of the same 3 Input items forming the Collection Application. The *Collection Physical* is used for a set of data items that represent data points collected at one geometric point. In the example, the suggested use is a pointer as indicated by the Usage item. Here the pointer usage refers to the mouse position coordinates and the system software will translate the mouse coordinates in movement of the screen cursor.

(4) Nested usage pages are also possible and give more details about a certain aspect within the general function of the device. In this case, two Inputs items are grouped and correspond to the buttons of the mouse. One Input item defines the three buttons of the mouse (right, left and wheel) in terms of number of data fields for the item (*Report Count* item), size of a data field (*Report Size* item) and possible values for each data field (*Usage Minimum* and *Maximum*, *Logical Minimum* and *Maximum* items). The other Input item is a 13-bit constant allowing the Input report data to be aligned on a byte boundary. This Input item is used only for padding purpose.

(5) Another nested usage page referring to a generic desktop control is defined for the mouse position coordinates. For this usage page, the Input item describes the data fields corresponding to the x- and y-axis as specified by the two Usage items.

After analyzing the previous mouse Report descriptor content, the host's HID parser is able to interpret the Input report data sent by the device with an interrupt IN transfer or in response to a `GET_REPORT` request. The Input report data corresponding to the mouse Report descriptor shown in Figure - Report Descriptor Content from a Host HID Parser View in the *HID Class Overview* page is presented in Table - Input Report Sent to Host and Corresponding to the State of a 3-Buttons Mouse in the *HID Class Overview* page. The total size of the report data is 4 bytes. Different types of reports may be sent over the same endpoint. For the purpose of distinguishing the different types of reports, a 1-byte report ID prefix is added to the data report. If a report ID was used in the example of the mouse report, the total size of the report data would be 5 bytes.

Bit offset	Bit count	Description
0	1	Button 1 (left button).
1	1	Button 2 (right button).
2	1	Button 3 (wheel button).
3	13	Not used.
16	8	Position on axis X.
24	8	Position on axis Y.

Table - Input Report Sent to Host and Corresponding to the State of a 3-Buttons Mouse

A Physical descriptor indicates the part or parts of the body intended to activate a control or controls. An application may use this information to assign a functionality to the control of a device. A Physical descriptor is an optional class-specific descriptor and most devices have little gain for using it. Refer to “Device Class Definition for Human Interface Devices (HID) Version 1.11” section 6.2.3 for more details about this descriptor.

HID Class Architecture

Figure - General Architecture Between a Host and HID Class in the *HID Class Architecture* page shows the general architecture between the host and the device using the HID class offered by Micriµm.

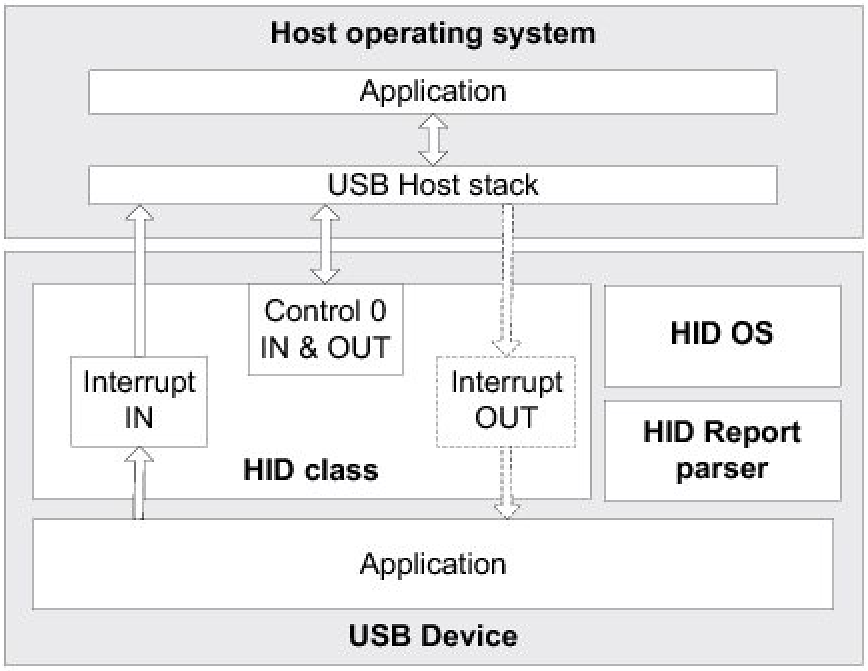


Figure - General Architecture Between a Host and HID Class

The host operating system (OS) enumerates the device using the control endpoints. Once the enumeration phase is done, the host starts the transmission/reception of reports to/from the device using the interrupt endpoints.

On the device side, the HID class interacts with an OS layer specific to this class. The HID OS layer provides specific OS services needed for the internal functioning of the HID class. This layer does not assume a particular OS. By default, Micrium provides the HID OS layer for µC/OS-II and µC/OS-III. If you need to port the HID class to your own OS, refer to the Porting the HID Class to an RTOS page for more details about the HID OS layer.

During the HID class initialization phase, a report parser module is used to validate the report provided by the application. If any error is detected during the report validation, the initialization will fail.

HID Class Configuration

Generic Configuration

Some constants are available to customize the class. These constants are located in the USB device configuration file, `usbd_cfg.h` . Table - HID Class Configuration Constants in the *HID Class Configuration* page shows their description.

Constant	Description	Possible Values
`USBD_HID_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances. Unless you plan on having multiple configurations or interfaces using different class instances, this can be set to the default value.	From 1 to 254. Default value is **1**.
`USBD_HID_CFG_MAX_NBR_CFG`	Configures the maximum number of configurations in which HID class is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed.	From 1 (low- and full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_HID_CFG_MAX_NBR_REPORT_ID`	Configures the maximum number of report IDs allowed in a report. The value should be set properly to accommodate the number of report ID to be used in the report.	From 1 to 65535. Default value is **1**.
`USBD_HID_CFG_MAX_NBR_REPORT_PUSHPOP`	Configures the maximum number of Push and Pop items used in a report. If the constant is set to **0**, no Push and Pop items are present in the report.	From 0 to 254. Default value is **0**.

Table - HID Class Configuration Constants

The HID class uses an internal task to manage periodic input reports. The task priority and stack size shown in Table - HID Internal Task’s Configuration Constants in the *HID Class Configuration* page are defined in the application configuration file, `app_cfg.h`. Refer to the HID Periodic Input Reports Task page for more details about the HID internal task.

Constant	Description	Possible Values
`USBD_HID_OS_CFG_TMR_TASK_PRIO`	Configures the priority of the HID periodic input reports task.	From the lowest to the highest priority supported by the OS used.
`USBD_HID_OS_CFG_TMR_TASK_STK_SIZE`	Configures the stack size of the HID periodic input reports task. The required size of the stack can greatly vary depending on the OS used, the CPU architecture, the type of application, etc. Refer to the documentation of the OS for more details about tasks and stack size calculation.	From the minimal to the maximal stack size supported by the OS used.

Table - HID Internal Task's Configuration Constants

Class Instance Configuration

Before starting the communication phase, your application needs to initialize and configure the class to suit its needs. Table - HID Class Initialization API Summary in the *HID Class Configuration* page summarizes the initialization functions provided by the HID class. For more details about the functions parameters, refer to the HID API Reference.

Function name	Operation
`USBD_HID_Init()`	Initializes HID class internal structures, variables and the OS layer.
`USBD_HID_Add()`	Creates a new instance of HID class.
`USBD_HID_CfgAdd()`	Adds an existing HID instance to the specified device configuration.

Table - HID Class Initialization API Summary

You need to call these functions in the order shown below to successfully initialize the HID class:

1. Call `USBD_HID_Init()`
   This is the first function you should call and you should do it only once even if you use multiple class instances. This function initializes all internal structures and variables that the class needs and also the HID OS layer.

2. Call `USBD_HID_Add()`
   This function allocates an HID class instance. It also allows you to specify the following instance characteristics:

   - The country code of the localized HID hardware.

- The Report descriptor content and size.
- The Physical descriptor content and size.
- The polling internal for the interrupt IN endpoint.
- The polling internal for the interrupt OUT endpoint.
- A flag enabling or disabling the Output reports reception with the control endpoint. When the control endpoint is not used, the interrupt OUT endpoint is used instead to receive Output reports.
- A structure that contains 4 application callbacks used for class-specific requests processing.

3. Call `USBD_HID_CfgAdd()`

Finally, once the HID class instance has been created, you must add it to a specific configuration.

Listing - HID Class Initialization Example in the *HID Class Configuration* page illustrates the use of the previous functions for initializing the HID class.

```
static  USBD_HID_CALLBACK  App_USBD_HID_Callback = {                          (3)
    App_USBD_HID_GetFeatureReport,
    App_USBD_HID_SetFeatureReport,
    App_USBD_HID_GetProtocol,
    App_USBD_HID_SetProtocol,
    App_USBD_HID_ReportSet
};

CPU_BOOLEAN  App_USBD_HID_Init (CPU_INT08U  dev_nbr,
                                CPU_INT08U  cfg_hs,
                                CPU_INT08U  cfg_fs)
{
    USBD_ERR    err;
    CPU_INT08U  class_nbr;


    USBD_HID_Init(&err);                                                      (1)
    if (err != USBD_ERR_NONE) {
        /* Handle the error. */
    }


    class_nbr = USBD_HID_Add(              USBD_HID_SUBCLASS_BOOT,            (2)
                                           USBD_HID_PROTOCOL_MOUSE,
                                           USBD_HID_COUNTRY_CODE_NOT_SUPPORTED,
                                          &App_USBD_HID_ReportDesc[0],
                                           sizeof(App_USBD_HID_ReportDesc),
                             (CPU_INT08U *)0,
                                           0u,
                                           2u,
                                           2u,
                                           DEF_YES,
                                          &App_USBD_HID_Callback,             (3)
                                          &err);
    if (err != USBD_ERR_NONE) {
        /* Handle the error. */
    }

    if (cfg_hs != USBD_CFG_NBR_NONE) {
        USBD_HID_CfgAdd(class_nbr, dev_nbr, cfg_hs, &err);                    (4)
        if (err != USBD_ERR_NONE) {
            /* Handle the error. */
        }
    }
    if (cfg_fs != USBD_CFG_NBR_NONE) {
        USBD_HID_CfgAdd(class_nbr, dev_nbr, cfg_fs, &err);                    (5)
        if (err != USBD_ERR_NONE) {
            /* Handle the error. */
        }
    }
}
```

Listing - HID Class Initialization Example

(1) Initialize HID internal structures, variables and OS layer.

(2) Create a new HID class instance. In this example, the subclass is “Boot”, the protocol is “Mouse” and the country code is unknown. A table, `App_USBD_HID_ReportDesc`[],

representing the Report descriptor is passed to the function (refer to Listing - Mouse Report Descriptor Example in the *HID Class Configuration* page for an example of Report descriptor content and to the Report section for more details about the Report descriptor format). No Physical descriptor is provided by the application. The interrupt IN endpoint is used and has a 2 frames or microframes polling interval. The use of the control endpoint to receive Output reports is enabled. The interrupt OUT endpoint will not be used. And therefore, the interrupt OUT polling interval of 2 is ignored by the class. The structure `App_USBD_HID_Callback` is also passed and references 4 application callbacks which will be called by the HID class upon processing of the class-specific requests.

(3) There are 5 application callbacks for class-specific requests processing. There is one callback for each of the following requests: `GET_REPORT`, `SET_REPORT`, `GET_PROTOCOL` and `SET_PROTOCOL`. Refer to “Device Class Definition for Human Interface Devices (HID) Version 1.11”, section 7.2 for more details about these class-specific requests.

(4) Check if the high-speed configuration is active and proceed to add the HID instance previously created to this configuration.

(5) Check if the full-speed configuration is active and proceed to add the HID instance to this configuration.

Listing - HID Class Initialization Example in the *HID Class Configuration* pagealso illustrates an example of multiple configurations. The functions `USBD_HID_Add()` and `USBD_HID_CfgAdd()` allow you to create multiple configurations and multiple instances architecture. Refer to Table - Constants and Functions Related to the Concept of Multiple Class Instances in the *Class Instance Concept* page for more details about multiple class instances.

Listing - Mouse Report Descriptor Example in the *HID Class Configuration* page presents an example of table declaration defining a Report descriptor corresponding to a mouse. The example matches the mouse report descriptor viewed by the host HID parser in Figure - Report Descriptor Content from a Host HID Parser View in the *HID Class Overview* page. The mouse report represents an Input report. Refer to the Report section for more details about the Report descriptor format. The items inside a collection are intentionally indented for code clarity.

```
static  CPU_INT08U  App_USBD_HID_ReportDesc[] = {                             (1) (2)
  USBD_HID_GLOBAL_USAGE_PAGE        + 1, USBD_HID_USAGE_PAGE_GENERIC_DESKTOP_CONTROLS,
  USBD_HID_LOCAL_USAGE              + 1, USBD_HID_CA_MOUSE,                    (3)
  USBD_HID_MAIN_COLLECTION          + 1, USBD_HID_COLLECTION_APPLICATION,      (4)
    USBD_HID_LOCAL_USAGE            + 1, USBD_HID_CP_POINTER,                  (5)
    USBD_HID_MAIN_COLLECTION        + 1, USBD_HID_COLLECTION_PHYSICAL,         (6)
      USBD_HID_GLOBAL_USAGE_PAGE    + 1, USBD_HID_USAGE_PAGE_BUTTON,           (7)
      USBD_HID_LOCAL_USAGE_MIN      + 1, 0x01,
      USBD_HID_LOCAL_USAGE_MAX      + 1, 0x03,
      USBD_HID_GLOBAL_LOG_MIN       + 1, 0x00,
      USBD_HID_GLOBAL_LOG_MAX       + 1, 0x01,
      USBD_HID_GLOBAL_REPORT_COUNT  + 1, 0x03,
      USBD_HID_GLOBAL_REPORT_SIZE   + 1, 0x01,
      USBD_HID_MAIN_INPUT           + 1, USBD_HID_MAIN_DATA     |
                                         USBD_HID_MAIN_VARIABLE |
                                         USBD_HID_MAIN_ABSOLUTE,
      USBD_HID_GLOBAL_REPORT_COUNT  + 1, 0x01,                                 (8)
      USBD_HID_GLOBAL_REPORT_SIZE   + 1, 0x0D,
      USBD_HID_MAIN_INPUT           + 1, USBD_HID_MAIN_CONSTANT,
                                                                               (9)
      USBD_HID_GLOBAL_USAGE_PAGE    + 1, USBD_HID_USAGE_PAGE_GENERIC_DESKTOP_CONTROLS,
      USBD_HID_LOCAL_USAGE          + 1, USBD_HID_DV_X,
      USBD_HID_LOCAL_USAGE          + 1, USBD_HID_DV_Y,
      USBD_HID_GLOBAL_LOG_MIN       + 1, 0x81,
      USBD_HID_GLOBAL_LOG_MAX       + 1, 0x7F,
      USBD_HID_GLOBAL_REPORT_SIZE   + 1, 0x08,
      USBD_HID_GLOBAL_REPORT_COUNT  + 1, 0x02,
      USBD_HID_MAIN_INPUT           + 1, USBD_HID_MAIN_DATA     |
                                         USBD_HID_MAIN_VARIABLE |
                                         USBD_HID_MAIN_RELATIVE,
    USBD_HID_MAIN_ENDCOLLECTION,                                              (10)
  USBD_HID_MAIN_ENDCOLLECTION                                                 (11)
};
```

Listing - Mouse Report Descriptor Example

(1) The table representing a mouse Report descriptor is initialized in such way that each line corresponds to a short item. The latter is formed from a 1-byte prefix and a 1-byte data. Refer to “Device Class Definition for Human Interface Devices (HID) Version 1.11”, sections 5.3 and 6.2.2.2 for more details about short items format. This table content corresponds to the mouse Report descriptor content viewed by a host HID parser in Figure - Report Descriptor Content from a Host HID Parser View in the *HID Class Overview* page .

(2) The Generic Desktop Usage Page is used.

(3) Within the Generic Desktop Usage Page, the usage tag suggests that the group of controls is for controlling a mouse. A mouse collection typically consists of two axes (X and Y) and one, two, or three buttons.

(4) The mouse collection is started.

(5) Within the mouse collection, a usage tag suggests more specifically that the mouse controls belong to the pointer collection. A pointer collection is a collection of axes that generates a value to direct, indicate, or point user intentions to an application.

(6) The pointer collection is started.

(7) The Buttons Usage Page defines an Input item composed of three 1-bit fields. Each 1-bit field represents the mouse's button 1, 2 and 3 respectively and can return a value of 0 or 1.

(8) The Input Item for the Buttons Usage Page is padded with 13 other bits.

(9) Another Generic Desktop Usage Page is indicated for describing the mouse position with the axes X and Y. The Input item is composed of two 8-bit fields whose value can be between -127 and 127.

(10) The pointer collection is closed.

(11) The mouse collection is closed.

Class Instance Communication

The HID class offers the following functions to communicate with the host. For more details about the functions parameters, refer to the HID API Reference.

Function name	Operation
`USBD_HID_Rd()`	Receives data from host through interrupt OUT endpoint. This function is blocking.
`USBD_HID_Wr()`	Sends data to host through interrupt IN endpoint. This function is blocking.
`USBD_HID_RdAsync()`	Receives data from host through interrupt OUT endpoint. This function is non-blocking.
`USBD_HID_WrAsync()`	Sends data to host through interrupt IN endpoint. This function is non-blocking.

Table - HID Communication API Summary

Synchronous Communication

Synchronous communication means that the transfer is blocking. Upon function call, the applications blocks until the transfer completion with or without an error. A timeout can be specified to avoid waiting forever.

Listing - Synchronous Bulk Read and Write Example in the *HID Class Configuration* page presents a read and write example to receive data from the host using the interrupt OUT endpoint and to send data to the host using the interrupt IN endpoint.

```
CPU_INT08U  rx_buf[2];
CPU_INT08U  tx_buf[2];
USBD_ERR    err;


(void)USBD_HID_Rd(         class_nbr,                                    (1)
                  (void *)&rx_buf[0],                                    (2)
                           2u,
                           0u,                                           (3)
                          &err);
if (err != USBD_ERR_NONE) {
    /* $$$$ Handle the error. */
}

(void)USBD_HID_Wr(         class_nbr,                                    (1)
                  (void *)&tx_buf[0],                                    (4)
                           2u,
                           0u,                                           (3)
                          &err);
if (err != USBD_ERR_NONE) {
    /* $$$$ Handle the error. */
}
```

Listing - Synchronous Bulk Read and Write Example

(1) The class instance number created from `USBD_HID_Add()` will serve internally for the HID class to route the transfer to the proper interrupt OUT or IN endpoint.

(2) The application must ensure that the buffer provided to the function is large enough to accommodate all the data. Otherwise, synchronization issues might happen. Internally, the read operation is done either with the control endpoint or with the interrupt endpoint depending on the control read flag set when calling `USBD_HID_Add()`.

(3) In order to avoid an infinite blocking situation, a timeout expressed in milliseconds can be specified. A value of ‘0’ makes the application task wait forever.

(4) The application provides the initialized transmit buffer.

Asynchronous Communication

Asynchronous communication means that the transfer is non-blocking. Upon function call, the application passes the transfer information to the device stack and does not block. Other application processing can be done while the transfer is in progress over the USB bus. Once the transfer is completed, a callback is called by the device stack to inform the application about the transfer completion.

Listing - Asynchronous Bulk Read and Write Example in the *HID Class Configuration* page shows an example of an asynchronous read and write.

```
void App_USBD_HID_Comm (CPU_INT08U  class_nbr)
{
    CPU_INT08U  rx_buf[2];
    CPU_INT08U  tx_buf[2];
    USBD_ERR    err;


    USBD_HID_RdAsync(         class_nbr,                                      (1)
                     (void *)&rx_buf[0],                                      (2)
                              2u,
                              App_USBD_HID_RxCmpl,                            (3)
                     (void *) 0u,                                             (4)
                             &err);
    if (err != USBD_ERR_NONE) {
        /* Handle the error. */
    }

    USBD_HID_WrAsync(         class_nbr,                                      (1)
                     (void *)&tx_buf[0],                                      (5)
                              2u,
                              App_USBD_HID_TxCmpl,                            (3)
                     (void *) 0u,                                             (4)
                             &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
}

static  void  App_USBD_HID_RxCmpl (CPU_INT08U   class_nbr,                    (3)
                                   void        *p_buf,
                                   CPU_INT32U   buf_len,
                                   CPU_INT32U   xfer_len,
                                   void        *p_callback_arg,
                                   USBD_ERR     err)
{
    (void)class_nbr;
    (void)p_buf;
    (void)buf_len;
    (void)xfer_len;
    (void)p_callback_arg;                                                     (4)

    if (err == USBD_ERR_NONE) {
        /* $$$$ Do some processing. */
    } else {
        /* $$$$ Handle the error. */
    }
}


static  void  App_USBD_HID_TxCmpl (CPU_INT08U   class_nbr,                    (3)
                                   void        *p_buf,
                                   CPU_INT32U   buf_len,
                                   CPU_INT32U   xfer_len,
                                   void        *p_callback_arg,
                                   USBD_ERR     err)
{
    (void)class_nbr;
    (void)p_buf;
    (void)buf_len;
    (void)xfer_len;
    (void)p_callback_arg;                                                     (4)

    if (err == USBD_ERR_NONE) {
        /* $$$$ Do some processing. */
    } else {
        /* $$$$ Handle the error. */
    }
}
```

Listing - Asynchronous Bulk Read and Write Example

(1) The class instance number serves internally for the HID class to route the transfer to the proper interrupt OUT or IN endpoint.

(2) The application must ensure that the buffer provided to the function is large enough to accommodate all the data. Otherwise, synchronization issues might happen. Internally, the read operation is done either with the control endpoint or with the interrupt endpoint depending on the control read flag set when calling `USBD_HID_Add()`.

(3) The application provides a callback passed as a parameter. Upon completion of the transfer, the device stack calls this callback so that the application can finalize the transfer by analyzing the transfer result. For instance, upon read operation completion, the application may do a certain processing with the received data. Upon write completion, the application may indicate if the write was successful and how many bytes were sent.

(4) An argument associated to the callback can be also passed. Then in the callback context, some private information can be retrieved.

(5) The application provides the initialized transmit buffer.

Using the HID Class Demo Application

Micrium provides a demo application that lets you test and evaluate the class implementation. Source template files are provided for the device. Executable and source files are provided for Windows host PC.

Note that the demo application provided by Micriµm is only an example and is intended to be used as a starting point to develop your own application.

Configuring PC and Device Applications

The HID class provides two demos:

- *Mouse* demo exercises Input reports sent to the host. Each report gives periodically the current state of a simulated mouse.
- *Vendor-specific* demo exercises Input and Output reports. The host sends an Output report or receives an Input report according to your choice.

On the device side, the demo application file, `app_usbd_hid.c`, offering the two HID demos is provided for µC/OS-II and µC/OS-III. It is located in this folder:

- `\Micrium\Software\uC-USB-Device-V4\App\Device\`

The use of these constants usually defined in `app_cfg.h` or `app_usbd_cfg.h` allows you to use one of the HID demos.

Constant	Description	File
`APP_CFG_USBD_HID_EN`	General constant to enable the HID class demo application. Must be set to `DEF_ENABLED`.	`app_usbd_cfg.h`
`APP_CFG_USBD_HID_TEST_MOUSE_EN`	Enables or disables the mouse demo. The possible values are `DEF_ENABLED` or `DEF_DISABLED`. If the constant is set to `DEF_DISABLED`, the vendor-specific demo is enabled.	`app_usbd_cfg.h`
`APP_CFG_USBD_HID_MOUSE_TASK_PRIO`	Priority of the task used by the mouse demo.	`app_cfg.h`
`APP_CFG_USBD_HID_READ_TASK_PRIO`	Priority of the read task used by the vendor-specific demo.	`app_cfg.h`
`APP_CFG_USBD_HID_WRITE_TASK_PRIO`	Priority of the write task used by the vendor-specific demo.	`app_cfg.h`
`APP_CFG_USBD_HID_TASK_STK_SIZE`	Stack size of the tasks used by mouse or vendor-specific demo. A default value can be 256.	`app_cfg.h`

Table - Device Application Constants Configuration

On the Windows side, the mouse demo influences directly the cursor on your monitor while the vendor-specific demo requires a custom application. The latter is provided by a Visual Studio solution located in this folder:

- `\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\HID\Visual Studio 2010`

The solution `HID.sln` contains two projects:

- "HID - Control" tests the Input and Output reports transferred through the control endpoints. The class-specific requests `GET_REPORT` and `SET_REPORT` allows the host to receive Input reports and send Output reports respectively.

- "HID - Interrupt" tests the Input and Output reports transferred through the interrupt IN and OUT endpoints.

An HID device is defined by a Vendor ID (VID) and Product ID (PID). The VID and PID will be retrieved by the host during the enumeration to build a string identifying the HID device. The "HID - Control" and "HID - Interrupt" projects contain both a file named `app_hid_common.c`. This file declares the following local constant:

```
static  const  TCHAR  App_DevPathStr[] = _TEXT("hid#vid_fffe&pid_1234");  (1)
```

Listing - Windows Application and String to Detect a Specific HID Device

(1) This constant allows the application to detect a specified HID device connected to the

host. The VID and PID given in `App_DevPathStr` variable must match with device side values. The device side VID and PID are defined in the `USBD_DEV_CFG` structure in the file `usbd_dev_cfg.c`. Refer to the Modify Device Configuration section for more details about the `USBD_DEV_CFG` structure. In this example, `VID = fffe` and `PID = 1234` in hexadecimal format.

Running the Demo Application

The *mouse demo* does not require anything on the Windows side. You just need to plug the HID device running the mouse demo to the PC and see the screen cursor moving.

Figure - HID Mouse Demo in the *Using the HID Class Demo Application* page presents the mouse demo with the host and device interactions:

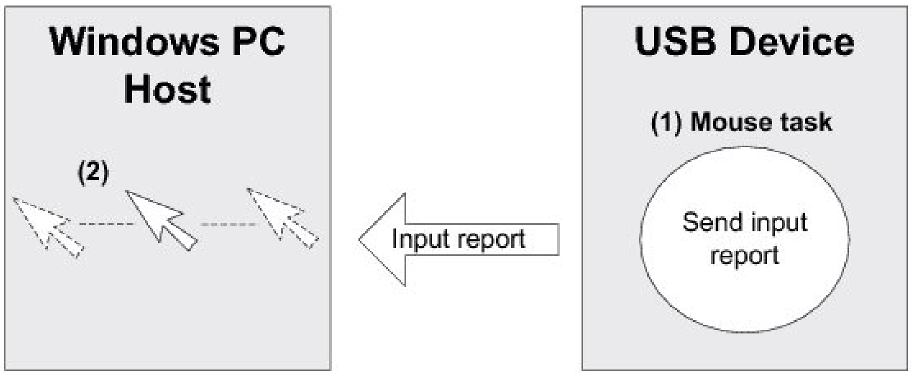


Figure - HID Mouse Demo

(1) On the device side, the task `App_USBD_HID_MouseTask()` simulates a mouse movement by setting the coordinates X and Y to a certain value and by sending the Input report that contains these coordinates. The Input report is sent by calling the `USBD_HID_Wr()` function through the interrupt IN endpoint. The mouse demo does not simulate any button clicks; only mouse movement.

(2) The host Windows PC polls the HID device periodically following the polling interval of the interrupt IN endpoint. The polling interval is specified in the Endpoint descriptor matching to the interrupt IN endpoint. The host receives and interprets the Input report content. The simulated mouse movement is translated into a movement of the screen cursor. While the device side application is running, the screen cursor moves endlessly.

The *vendor-specific demo* requires you to launch a Windows executable. Two executables are already provided in the following folder:

- `\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\HID\Visual Studio 2010\exe\`

The two executables have been generated with a Visual Studio 2010 project available in `\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\HID\Visual Studio 2010\`.

- *HID - Control.exe* for the vendor-specific demo utilizing the control endpoints to send Output reports or receive Input reports.

- *HID - Interrupt.exe* for the vendor-specific demo utilizing the interrupt endpoints to send Output reports or receive Input reports.

Figure - HID Vendor-Specific Demo in the *Using the HID Class Demo Application* page presents the vendor-specific demo with the host and device interactions:

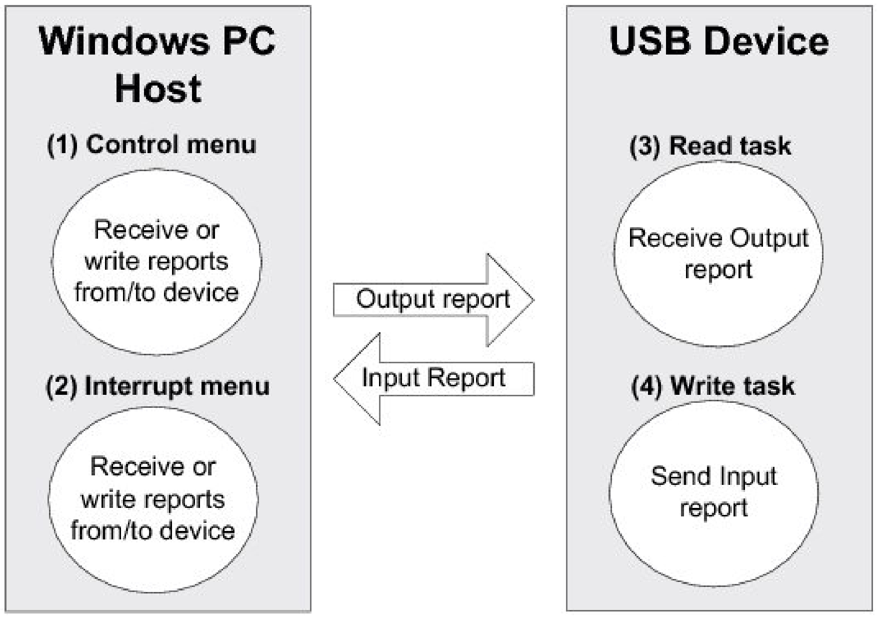


Figure - HID Vendor-Specific Demo

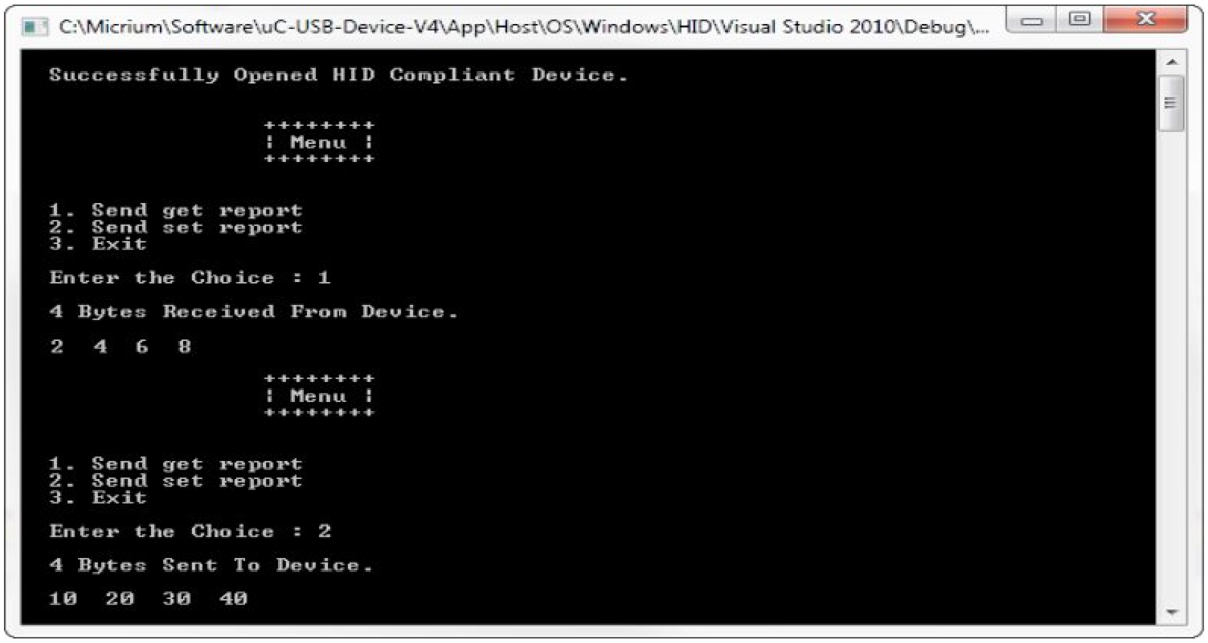
(1) A menu will appear after launching *HID - Control.exe*. You will have three choices: “1. Sent get report”, “2. Send set report” and “3. Exit”. Choice 1 will send a `GET_REPORT` request to obtain an Input report from the device. The content of the Input report will be displayed in the console. Choice 2 will send a `SET_REPORT` request to send an Output report to the device.

(2) A menu will appear after launching *HID - Interrupt.exe*. You will have three choices: “1. Read from device”, “2. Write from device” and “3. Exit”. The choice 1 will initiate an interrupt IN transfer to obtain an Input report from the device. The content of the Input report will be displayed in the console. Choice 2 will initiate an interrupt OUT transfer to send an Output report to the device.

(3) On the device side, the task `App_USBD_HID_ReadTask()` is used to receive Output reports from the host. The synchronous HID read function, `USBD_HID_Rd()`, will receive the Output report data. Nothing is done with the received data. The Output report has a size of 4 bytes.

(4) Another task, `App_USBD_HID_WriteTask()`, will send Input reports to the host using the synchronous HID write function, `USBD_HID_Wr()`. The Input report has a size of 4 bytes.

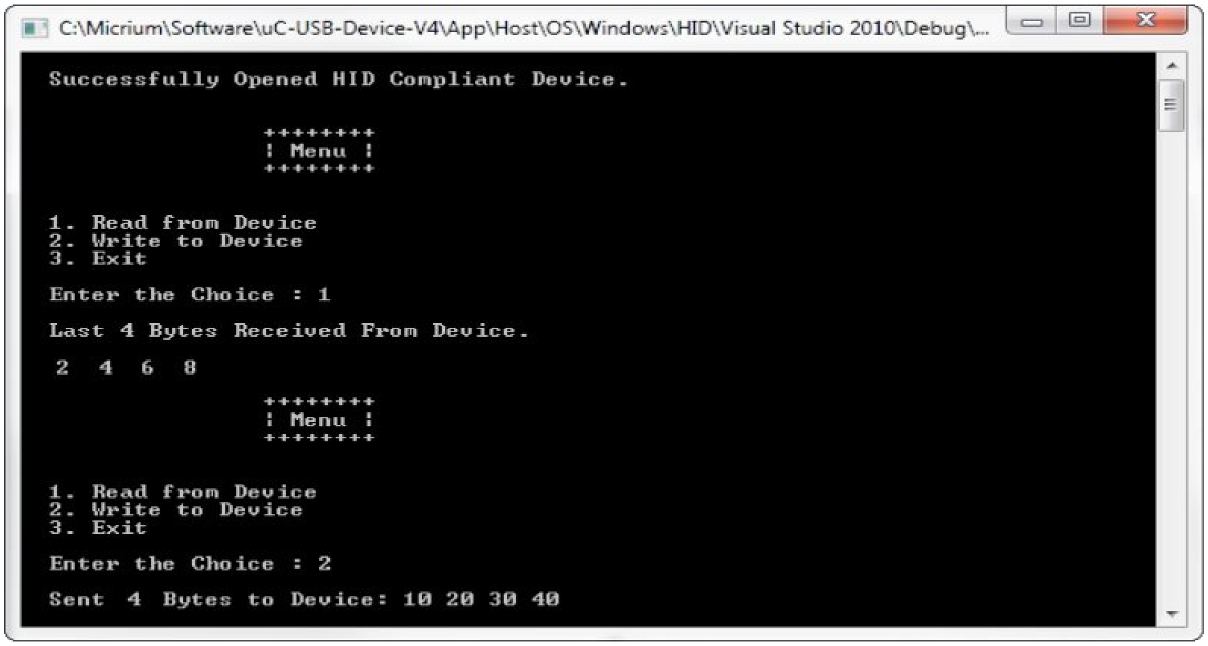
Figure - HID - Control.exe (Vendor-Specific Demo) in the *Using the HID Class Demo Application* page and Figure - HID - Interrupt.exe (Vendor-Specific Demo) in the *Using the HID Class Demo Application* page show screenshot examples corresponding to HID - Control.exe and HID - Interrupt.exe respectively.



C:\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\HID\Visual Studio 2010\Debug\...

```
Successfully Opened HID Compliant Device.

               ++++++++
               | Menu |
               ++++++++

1. Send get report
2. Send set report
3. Exit

Enter the Choice : 1

4 Bytes Received From Device.

2  4  6  8
               ++++++++
               | Menu |
               ++++++++

1. Send get report
2. Send set report
3. Exit

Enter the Choice : 2

4 Bytes Sent To Device.

10  20  30  40
```

Figure - HID - Control.exe (Vendor-Specific Demo)



C:\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\HID\Visual Studio 2010\Debug\...

```
Successfully Opened HID Compliant Device.

               ++++++++
               | Menu |
               ++++++++

1. Read from Device
2. Write to Device
3. Exit

Enter the Choice : 1

Last 4 Bytes Received From Device.

 2  4  6  8
               ++++++++
               | Menu |
               ++++++++

1. Read from Device
2. Write to Device
3. Exit

Enter the Choice : 2

Sent  4 Bytes to Device: 10 20 30 40
```

Figure - HID - Interrupt.exe (Vendor-Specific Demo)

Porting the HID Class to an RTOS

The HID class uses its own RTOS layer for different purposes:

- A locking system is used to protect a given Input report. A host can get an Input report by sending a `GET_REPORT` request to the device using the control endpoint or with an interrupt IN transfer. `GET_REPORT` request processing is done by the device stack while the interrupt IN transfer is done by the application. When the application executes the interrupt IN transfer, the Input report data is stored internally. This report data stored will be sent via a control transfer when `GET_REPORT` is received. The locking system ensures the data integrity between the Input report data storage operation done within an application task context and the `GET_REPORT` request processing done within the device stack's internal task context.

- A locking system is used to protect the Output report processing between an application task and the device stack's internal task when the control endpoint is used. The application provides to the HID class a receive buffer for the Output report in the application task context. This receive buffer will be used by the device stack's internal task upon reception of a `SET_REPORT` request. The locking system ensures the receive buffer and related variables integrity.

- A locking system is used to protect the interrupt IN endpoint access from multiple application tasks.

- A synchronization mechanism is used to implement the blocking behavior of `USBD_HID_Rd()` when the control endpoint is used.

- A synchronization mechanism is used to implement the blocking behavior of `USBD_HID_Wr()` because the HID class internally uses the asynchronous interrupt API for HID write.

- A task is used to process periodic Input reports. Refer to the Periodic Input Reports Task page for more details about this task.

By default, Micrium will provide an RTOS layer for both C/OS-II and C/OS-III. However, it is possible to create your own RTOS layer. Your layer will need to implement the functions listed in Table - HID OS Layer API Summary in the *Porting the HID Class to an RTOS* page. For a complete API description, refer to the HID API Reference.

Function name	Operation
`USBD_HID_OS_Init`	Creates and initializes the task and semaphores.
`USBD_HID_OS_InputLock`	Locks Input report.
`USBD_HID_OS_InputUnlock`	Unlocks Input report.
`USBD_HID_OS_InputDataPend`	Waits for Input report data write completion.
`USBD_HID_OS_InputDataPendAbort`	Aborts the wait for Input report data write completion.
`USBD_HID_OS_InputDataPost`	Signals that Input report data has been sent to the host.
`USBD_HID_OS_OutputLock`	Locks Output report.
`USBD_HID_OS_OutputUnlock`	Unlocks Output report.
`USBD_HID_OS_OutputDataPend`	Waits for Output report data read completion.
`USBD_HID_OS_OutputDataPendAbort`	Aborts the wait for Output report data read completion.
`USBD_HID_OS_OutputDataPost`	Signals that Output report data has been received from the host.
`USBD_HID_OS_TxLock`	Locks class transmit.
`USBD_HID_OS_TxUnlock`	Unlocks class transmit.
`USBD_HID_OS_TmrTask`	Task processing periodic input reports. Refer to the Periodic Input Reports Task page for more details about this task.

Table - HID OS Layer API Summary

HID Periodic Input Reports Task

In order to save bandwidth, the host has the ability to silence a particular report in an interrupt IN endpoint by limiting the reporting frequency. The host sends the `SET_IDLE` request to realize this operation. The HID class implemented by Micrium contains an internal task responsible for respecting the reporting frequency limitation applying to one or several input reports. Figure - Periodic Input Reports Task in the *HID Periodic Input Reports Task* page shows the periodic input reports tasks functioning.

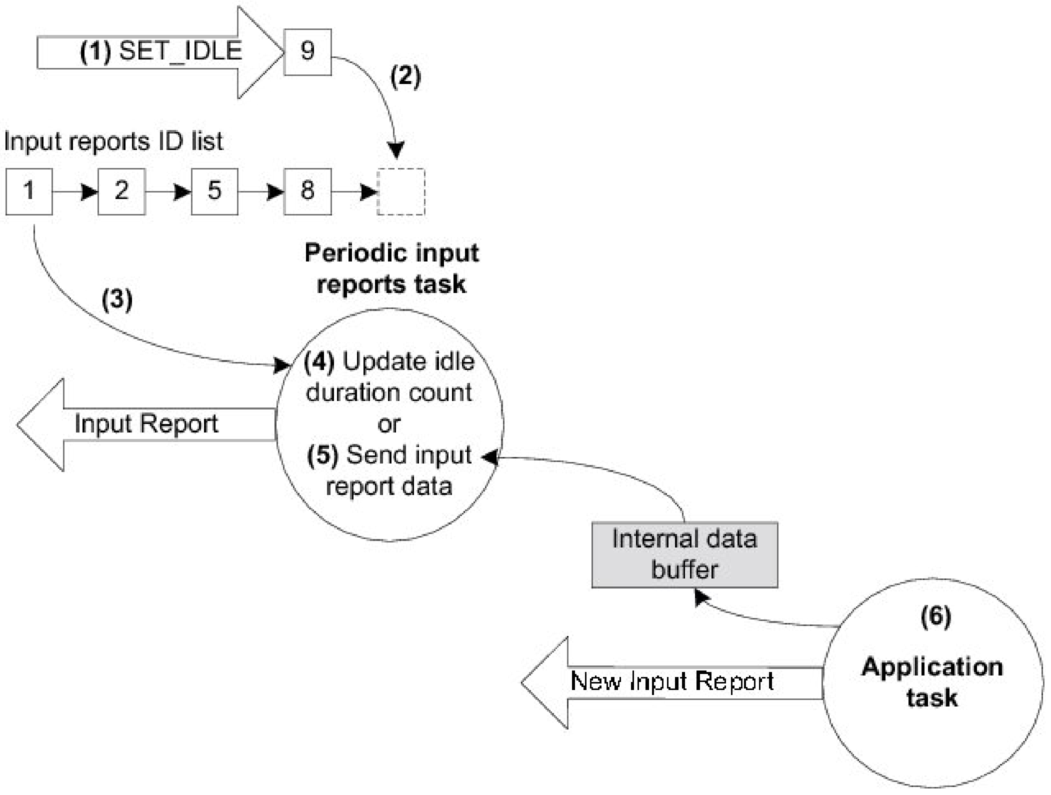


Figure - Periodic Input Reports Task

(1) The device receives a `SET_IDLE` request. This request specifies an idle duration for a given report ID. Refer to “Device Class Definition for Human Interface Devices (HID) Version 1.11”, section 7.2.4 for more details about the `SET_IDLE` request. A report ID allows you to distinguish among the different types of reports sent over the same endpoint.

(2) A report ID structure allocated during the HID class initialization phase is updated with the idle duration. An idle duration counter is initialized with the idle duration value. Then the report ID structure is inserted at the end of a linked list containing input reports ID structures. The idle duration value is expressed in 4-ms unit which gives a range of 4 to 1020 ms. If the idle duration is less than the interrupt IN endpoint polling interval, the reports are generated at the polling interval.

(3) Every 4 ms, the periodic input report task browses the input reports ID list. For each input report ID, the task performs one of two possible operations. The task period matches the 4-ms unit used for the idle duration. If no `SET_IDLE` requests have been sent by the host, the input reports ID list is empty and the task has nothing to process. The task processes only report IDs different from 0 and with an idle duration greater than 0.

(4) For a given input report ID, the task verifies if the idle duration has elapsed. If the idle duration has not elapsed, the counter is decremented and no input report is sent to the host.

(5) If the idle duration has elapsed, that is the idle duration counter has reached zero, an input report is sent to the host by calling the `USBD_HID_Wr()` function via the interrupt IN endpoint.

(6) The input report data sent by the task comes from an internal data buffer allocated for each input report described in the Report descriptor. An application task can call the `USBD_HID_Wr()` function to send an input report. After sending the input report data, `USBD_HID_Wr()` updates the internal buffer associated to an input report ID with the data just sent. Then, the periodic input reports task always sends the same input report data after each idle duration elapsed and until the application task updates the data in the internal buffer. There is some locking mechanism to avoid corruption of the input report ID data in the event of a modification happening at the exact time of transmission done by the periodic input report task.

The periodic input reports task is implemented in the HID OS layer in the function `USBD_HID_OS_TmrTask()`. Refer to the HID OS Functions reference for more details about this function.

Mass Storage Class

This section describes the mass storage device class (MSC) supported by C/USB-Device. The MSC implementation offered by C/USB-Device is in compliance with the following specifications:

- *Universal Serial Bus Mass Storage Class Specification Overview*, Revision 1.3 Sept. 5, 2008.
- *Universal Serial Bus Mass Storage Class Bulk-Only Transport*, Revision 1.0 Sept. 31, 1999.

MSC is a protocol that enables the transfer of information between a USB device and a host. The information is anything that can be stored electronically: executable programs, source code, documents, images, configuration data, or other text or numeric data. The USB device appears as an external storage medium to the host, enabling the transfer of files via drag and drop.

A file system defines how the files are organized in the storage media. The USB mass storage class specification does not require any particular file system to be used on conforming devices. Instead, it provides a simple interface to read and write sectors of data using the Small Computer System Interface (SCSI) transparent command set. As such, operating systems may treat the USB drive like a hard drive and can format it with any file system they like.

The USB mass storage device class supports two transport protocols:

- Bulk-Only Transport (BOT)
- Control/Bulk/Interrupt (CBI) Transport.

The mass storage device class supported by C/USB-Device implements the SCSI transparent command set using the BOT protocol only, which signifies that only bulk endpoints will be used to transmit data and status information. The MSC implementation supports multiple logical units and provides a high-level lock mechanism for storage media shared with an embedded file system.

MSC Overview

Protocol

The MSC protocol is composed of three phases:

- The Command Transport
- The Data Transport
- The Status Transport

Mass storage commands are sent by the host through a structure called the Command Block Wrapper (CBW). For commands requiring a data transport stage, the host will attempt to send or receive the exact number of bytes from the device as specified by the length and flag fields of the CBW. After the data transport stage, the host attempts to receive a Command Status Wrapper (CSW) from the device detailing the status of the command as well as any data residue (if any). For commands that do not include a data transport stage, the host attempts to receive the CSW directly after CBW is sent. The protocol is detailed in Figure - MSC Protocol in the *MSC Overview* page.

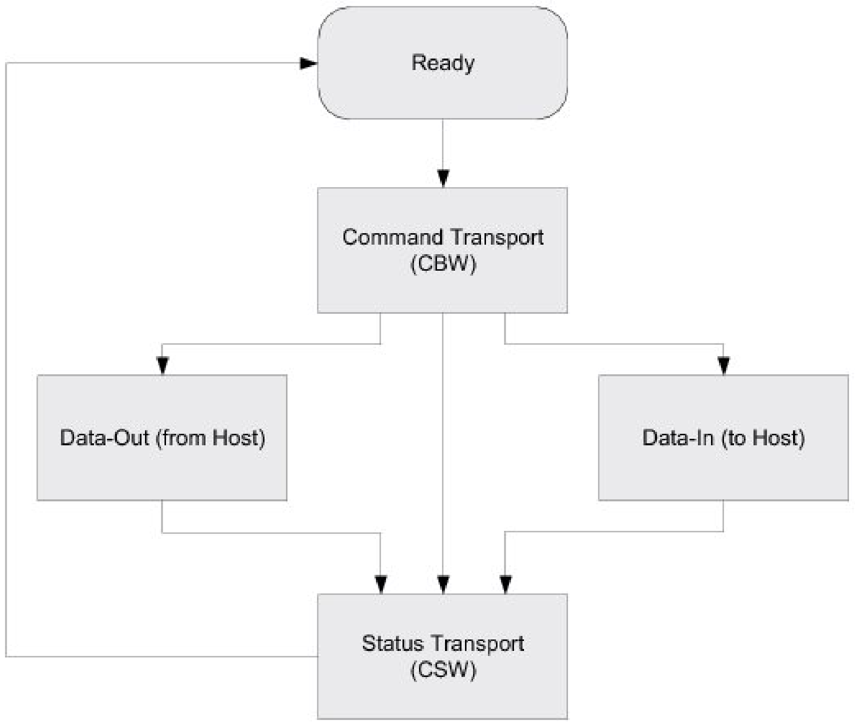


Figure - MSC Protocol

Endpoints

On the device side, in compliance with the BOT specification, the MSC is composed of the following endpoints:

- A pair of control IN and OUT endpoints called default endpoint.
- A pair of bulk IN and OUT endpoints.

Table - MSC Endpoint Usage in the *MSC Overview* page indicates the different usages of the endpoints.

Endpoint	Direction	Usage
Control IN Control OUT	Device to Host Host to Device	Enumeration and MSC class-specific requests
Bulk IN Bulk OUT	Device to Host Host to Device	Send CSW and data Receive CBW and data

Table - MSC Endpoint Usage

Class Requests

There are two defined control requests for the MSC BOT protocol. These requests and their descriptions are detailed in Table - Mass Storage Class Requests in the *MSC Overview* page.

Class Requests	Description
Bulk-Only Mass Storage Reset	This request is used to reset the mass storage device and its associated interface. This request readies the device to receive the next command block.
Get Max LUN	This request is used to return the highest logical unit number (LUN) supported by the device. For example, a device with LUN 0 and LUN 1 will return a value of 1. A device with a single logical unit will return 0 or stall the request. The maximum value that can be returned is 15.

Table - Mass Storage Class Requests

Small Computer System Interface (SCSI)

SCSI is a set of standards for handling communication between computers and peripheral devices. These standards include commands, protocols, electrical interfaces and optical interfaces. Storage devices that use other hardware interfaces such as USB, use SCSI commands for obtaining device/host information and controlling the device's operation and transferring blocks of data in the storage media.

SCSI commands cover a vast range of device types and functions and as such, devices need a subset of these commands. In general, the following commands are necessary for basic communication:

- INQUIRY
- READ CAPACITY(10)
- READ(10)
- REQUEST SENSE
- TEST UNIT READY
- WRITE(10)

Refer to Table - SCSI Commands in the *MSC Architecture* page to see the full list of implemented SCSI commands by μC/USB-Device.

MSC Architecture

Overview

Figure - MSC Architecture in the *MSC Architecture* page shows the general architecture of a USB Host and a USB MSC Device.

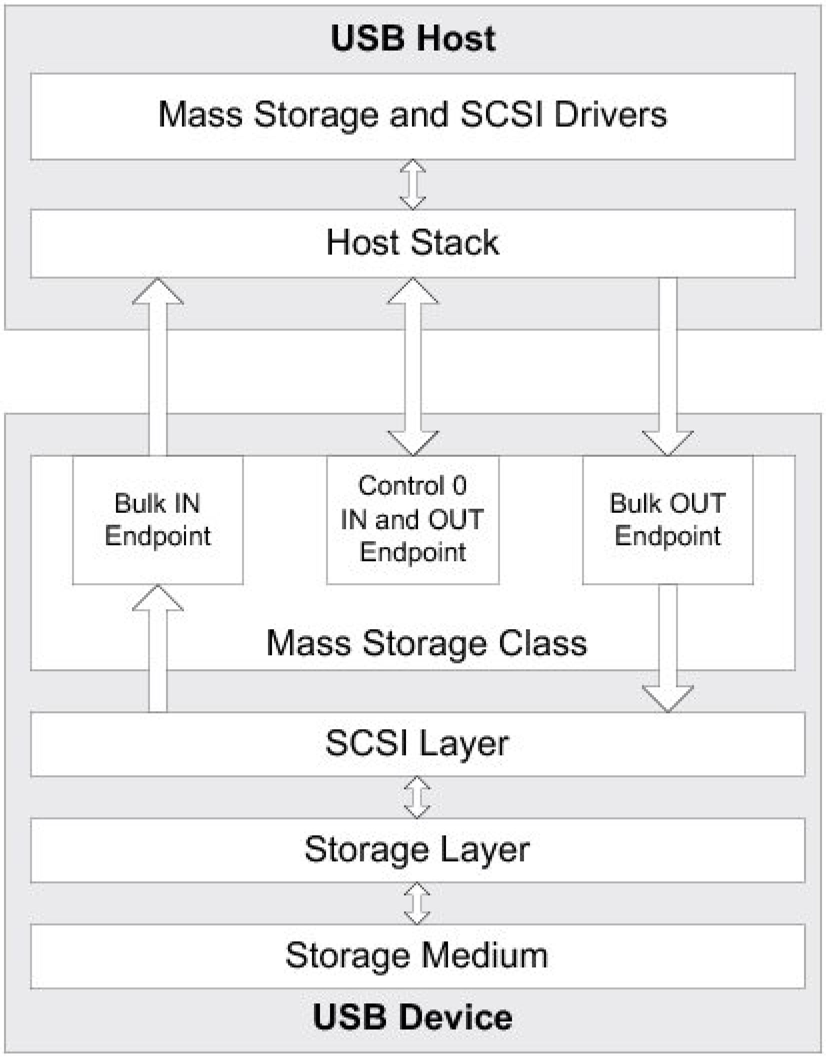


Figure - MSC Architecture

On the host side, the application communicates with the MSC device by interacting with the native mass storage drivers and SCSI drivers. In compliance with the BOT specification, the host utilizes the default control endpoint to enumerate the device and the Bulk IN/OUT endpoints to communicate with the device.

SCSI Commands

The host sends SCSI commands to the device via the Command Descriptor Block (CDB). These commands set specific requests for transfer of blocks of data and status, and control information such as a device's capacity and readiness to exchange data. The C/USB MSC Device supports the following subset of SCSI Primary and Block Commands listed in Table - SCSI Commands in the *MSC Architecture* page.

SCSI Command	Function
INQUIRY	Requests the device to return a structure that contains information about itself. A structure shall be returned by the device despite of the media's readiness to respond to other commands. Refer to SCSI Primary Commands documentation for the full command description.
TEST UNIT READY	Requests the device to return a status to know if the device is ready to use. Refer to SCSI Primary Commands documentation for the full command description.
READ CAPACITY (10) READ CAPACITY (16)	Requests the device to return how many bytes a device can store. Refer to SCSI Block Commands documentation for the full command description.
READ (10) READ (12) READ (16)	Requests to read a block of data from the device's storage media. Please refer to SCSI Block Commands documentation for the full command description.
WRITE (10) WRITE (12) WRITE (16)	Requests to write a block of data to the device's storage media. Refer to SCSI Block Commands documentation for the full command description.
VERIFY (10) VERIFY (12) VERIFY (16)	Requests the device to test one or more sectors. Refer to SCSI Block Commands documentation for the full command description.
MODE SENSE (6) MODE SENSE (10)	Requests parameters relating to the storage media, logical unit or the device itself. Refer to SCSI Primary Commands documentation for the full command description.
REQUEST SENSE	Requests a structure containing sense data. Refer to SCSI Primary Commands documentation for the full command description.
PREVENT ALLOW MEDIA REMOVAL	Requests the device to prevent or allow users to remove the storage media from the device. Refer to SCSI Primary Commands documentation for the full command description.
START STOP UNIT	Requests the device to load or eject the medium. Refer to SCSI Block Commands documentation for the full command description.

Table - SCSI Commands

Storage Layer and Storage Medium

The storage layer shown in Figure - MSC Architecture in the *MSC Architecture* page is the interface between the MSC and the storage medium. The storage layer is responsible for initializing the storage medium, performing read / write operations on it, as well as obtaining information regarding its capacity and status. The storage medium could be:

- RAM
- SD/CF card
- NAND flash
- NOR flash
- IDE hard disk drive

The MSC can interface with three types of storage layer:

- RAM disk
- µC/FS
- Vendor-specific file system

By default, Micrium will provide a storage layer implementation (named RAMDisk) by utilizing the hardware's platform memory as storage medium. Aside from this implementation, you have the option to use Micrium's µC/FS or even utilize your own file system referred as vendor-specific file system storage layer. In the event you use your own file system, you will need to create a storage layer port to communicate with the storage medium. Please refer to the Porting MSC to a Storage Layer page to learn how to implement this storage layer.

Figure - µC/FS Storage layer in the *MSC Architecture* page shows how the µC/FS storage layer interfaces with µC/FS.

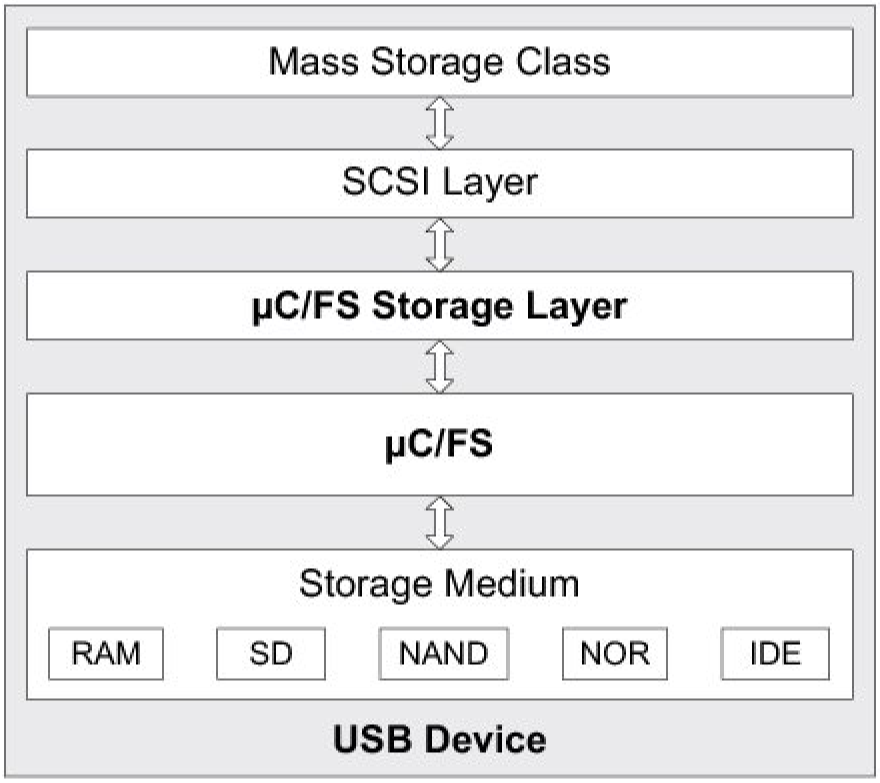


Figure - µC/FS Storage layer

µC/FS storage layer implementation has two main characteristics:

- High-level lock mechanism.
- Insertion/removal detection of removable media.

The high-level lock mechanism protects the storage medium from concurrent accesses that could occur between a host computer and an embedded µC/FS application. On one hand, if a mass storage device is connected to a host computer and the storage medium is available, the host computer has the exclusive control of the storage medium. No embedded µC/FS application can access the storage medium. The µC/FS application will wait until the lock has been released. The lock is released upon device disconnection from the host or by a software eject done on the medium from the host side. On the other hand, if a µC/FS application has already the lock on the storage medium, upon device connection, the host won't have access. Each time the host requests the storage medium presence status, the mass storage device will indicate that the medium is not present. This status is returned as long as µC/FS application holds the lock. As soon as the lock is released, the host takes it and no more µC/FS operations on the storage medium are possible.

µC/FS storage layer is able to detect the insertion or removal of a removable media such as SD card. A task is used to detect the insertion or removal. The task checks periodically the presence or absence of a removable media. When the mass storage device is connected and the removable media is not present, the mass storage device indicates to the host that the storage medium is not present. As soon as the removable media is inserted in its slot, the task in µC/FS storage layer updates the removable media presence status. Next time the host requests the presence status, the mass storage device returns a good status and the host can access the content of the removable media. The opposite reasoning applies to media removal. If your product uses only fixed media, the task in µC/FS storage layer can be disabled. You can also configure the task's period. Refer to the General Configuration section for more details about µC/FS storage layer configuration.

Multiple Logical Units

The MSC class supports multiple logical units. A logical unit designates usually an entire media type or a partition within the same media type. Figure - Example of Logical Units Configurations in the *MSC Architecture* page illustrates the different multiple logical units configurations supported.

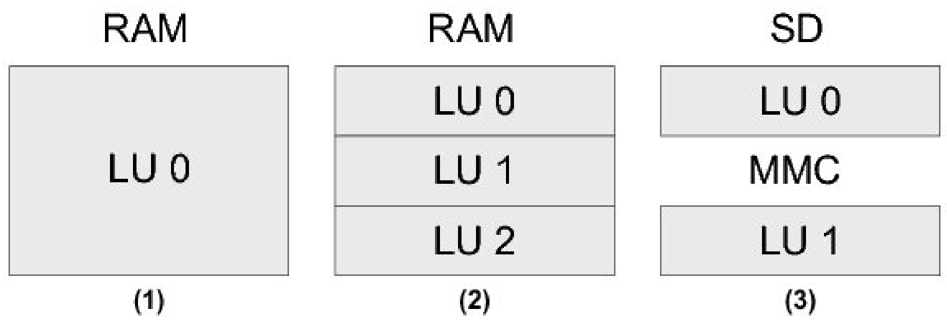


Figure - Example of Logical Units Configurations

(1) Configuration #1 is an example of single logical unit. The whole RAM region represents one unique logical unit. This configuration is a typical example of USB memory sticks. When the device is connected to a host, this one will display a media icon.

(2) Configuration #2 is an example of multiple logical units within the same media. Each logical unit could be seen as a partition. This configuration is a typical example of USB external hard drive. When the device is connected to the host, this one will display three

media icons.

(3) Configuration #3 is an example of multiple logical units of different type. This configuration a a typical example of multi-card reader.

Configurations #1 and #2 are supported by the RAMDisk storage layer. Configurations #1 and #3 are supported by the μC/FS storage layer. The configuration #2 is currently not supported by the μC/FS storage layer.

Each logical unit is added to the MSC at initialization. Refer to the Class Instance Configuration section for more details about the multiple logical units initialization and to the MSC Host Application section for a Windows example of multiple logical units.

MSC RTOS Layer

General Information

MSC device communication relies on a task handler that implements the MSC protocol. This task handler needs to be notified when the device is properly enumerated before communication begins. Once communication begins, the task must also keep track of endpoint update statuses to correctly implement the MSC protocol. These types of notification are handled by RTOS signals. For the MSC RTOS layer, there are two semaphores created. One for enumeration process and one for communication process. By default, Micrium will provide RTOS layers for both µC/OS-II and µC/OS-III. However, it is also possible to create your own RTOS layer. Please refer to the Porting MSC to an RTOS page to learn how to port to a different RTOS.

Mass Storage Task Handler

The MSC task handler implements the MSC protocol, responsible for the communication between the device and the host. The task handler is initialized when USBD_MSC_Init() is called. The MSC protocol is handled by a state machine comprised of 9 states. The transition between these states are detailed in Figure - MSC State Machine in the *MSC RTOS Layer* page.

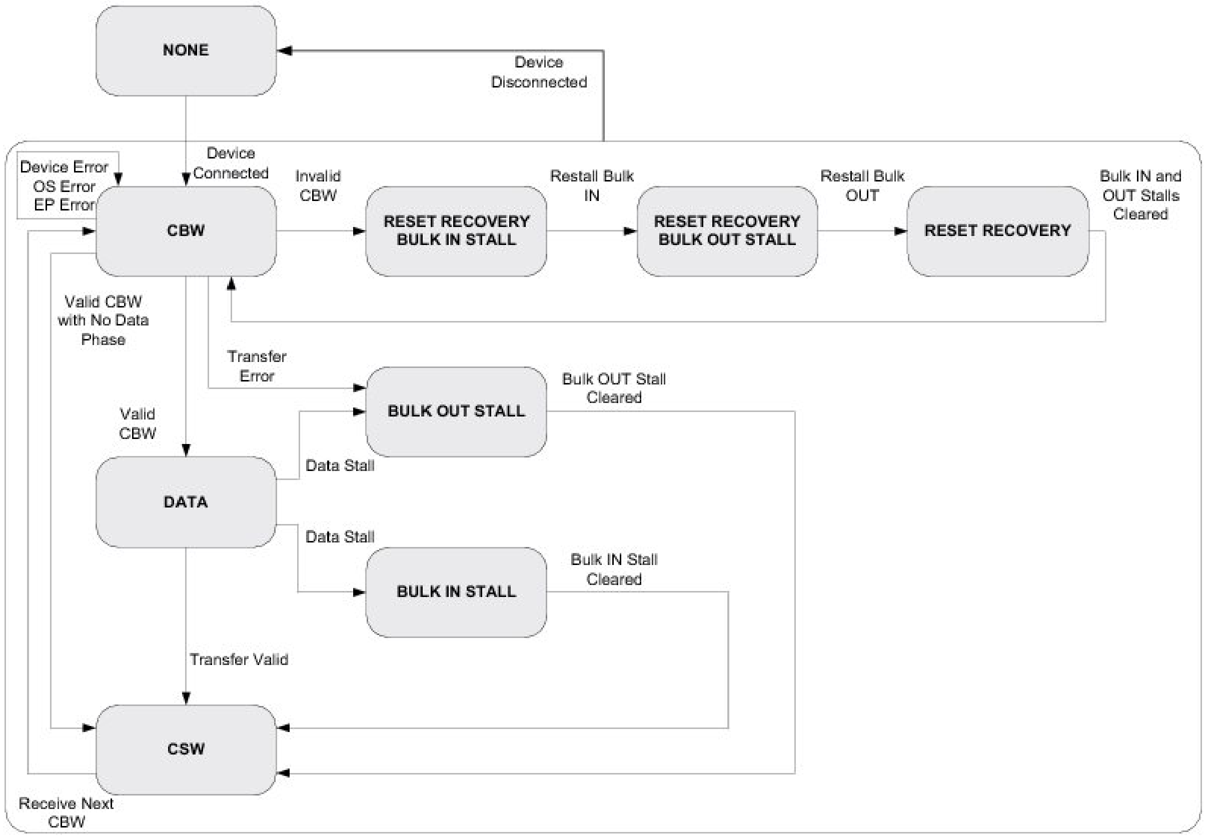


Figure - MSC State Machine

Upon detecting that the MSC device is connected, the device enters an infinite loop, waiting to receive the first CBW from the host. Depending on the command received, the device will either enter the data phase or transmit CSW phase. In the event of any stall conditions in the data phase, the host must clear the respective endpoint before transitioning to the CSW phase. If an invalid CBW is received from the host, the device enters the reset recovery state, where both endpoints are stalled, to complete the full reset with the host issuing the Bulk-Only Mass Storage Reset Class Request. After a successful CSW phase or a reset recovery, the task will return to receive the next CBW command. If at any stage the device is disconnected from the host, the state machine will transition to the None state.

MSC Configuration

General Configuration

There are various configuration constants necessary to customize the MSC device. These constants are located in the usbd_cfg.h file. Table - MSC Configuration Constants in the *MSC Configuration* page shows a description of each constant.

Constant	Description	Possible Values
`USBD_MSC_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances. Unless you plan having multiple configuration or interfaces using different class instances, this should be set to **1**.	From 1 to 254. Default value is **1**.
`USBD_MSC_CFG_MAX_NBR_CFG`	Configures the maximum number of configuration in which MSC is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed.	From 1 (low- and full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_MSC_CFG_MAX_LUN`	Configures the maximum number of logical units.	From 1 to 255. Default value is **1**.
`USBD_MSC_CFG_DATA_LEN`	Configures the read/write data length in octets.	Higher than 0. The default value is **2048.**
`USBD_MSC_CFG_FS_REFRESH_TASK_EN`	Enables or disables the use of a task in µC/FS storage layer for removable media insertion/removal detection. If only fixed media such as RAM, NAND are used, this constant should be set to `DEF_DISABLED`. Otherwise, `DEF_ENABLED` should be set.	`DEF_ENABLED` or **`DEF_DISABLED`**
`USBD_MSC_CFG_DEV_POLL_DLY_mS`	Configures the period of the µC/FS storage layer's task. It is expressed in milliseconds. If `USBD_MSC_CFG_FS_REFRESH_TASK_EN` is set to `DEF_DISABLED`, this constant has no effect. A faster period may improve the delay to detect the removable media insertion/removal resulting in a host computer displaying the removable media icon promptly. But the CPU will be interrupted often to check the removable media status. A slower period may result in a certain delay for the host computer to display the removable media icon. But the CPU will spend less time verifying the removable media status.	The default value is **100** ms.

Table - MSC Configuration Constants

Since MSC device relies on a task handler to implement the MSC protocol, this OS-task's priority and stack size constants need to be configured if µC/OS-II or µC/OS-III RTOS is used. Moreover if `USBD_MSC_CFG_FS_REFRESH_TASK_EN` is set to `DEF_ENABLED`, the µC/FS storage layer task's priority and stack size need also to be configured. These constants are summarized in Table - MSC OS-Task Handler Configuration Constants in the *MSC Configuration* page.

Constant	Description	Possible Values
`USBD_MSC_OS_CFG_TASK_PRIO`	MSC task handler's priority level. The priority level must be lower (higher valued) than the start task and core task priorities.	From the lowest to the highest priority supported by the OS used.
`USBD_MSC_OS_CFG_TASK_STK_SIZE`	MSC task handler's stack size. The required size of the stack can greatly vary depending on the OS used, the CPU architecture, the type of application, etc. Refer to the documentation of the OS for more details about tasks and stack size calculation.	From the minimal to the maximal stack size supported by the OS used. Default value is set to **256**.
`USBD_MSC_OS_CFG_REFRESH_TASK_PRIO`	µC/FS storage layer task's priority level. The priority level must be lower (higher valued) than the MSC task.	From the lowest to the highest priority supported by the OS used.
`USBD_MSC_OS_CFG_REFRESH_TASK_STK_SIZE`	µC/FS storage layer task's stack size. The required size of the stack can greatly vary depending on the OS used, the CPU architecture, the type of application, etc. Refer to the documentation of the OS for more details about tasks and stack size calculation.	From the minimal to the maximal stack size supported by the OS used. Default value is set to **256**.

Table - MSC OS-Task Handler Configuration Constants

Class Instance Configuration

Before starting the communication phase, your application needs to initialize and configure the class to suit its needs. Table - Class Instance API Functions in the *MSC Configuration* page summarizes the initialization functions provided by the MSC implementation. Please refer to the MSC Functions reference for a full listing of the MSC API.

Function name	Operation
`USBD_MSC_Init()`	Initializes MSC internal structures and variables.
`USBD_MSC_Add()`	Adds a new instance of the MSC.
`USBD_MSC_CfgAdd()`	Adds existing MSC instance into USB device configuration.
`USBD_MSC_LunAdd()`	Adds a LUN to the MSC interface.

Table - Class Instance API Functions

To successfully initialize the MSC, you need to follow these steps:

1. Call `USBD_MSC_Init()`
   This is the first function you should call, and it should be called only once regardless of the number of class instances you intend to have. This function will initialize all internal structures and variables that the class will need. It will also initialize the real-time operating system (RTOS) layer.

2. Call `USBD_MSC_Add()`
   This function will add a new instance of the MSC.

3. Call `USBD_MSC_CfgAdd()`
   Once the class instance is correctly configured and initialized, you will need to add it to a USB configuration. High speed devices will build two separate configurations, one for full speed and one for high speed by calling `USBD_MSC_CfgAdd()` for each speed configuration.

4. Call `USBD_MSC_LunAdd()`

Lastly, you add a logical unit to the MSC interface by calling this function. You will specify the type and volume of the logical unit you want to add as well as device details such as vendor ID string, product ID string, product revision level and read only flag. Logical units are identified by a string name composed of the storage device driver name and the logical unit number as follows: <device_driver_name>:<logical_unit_number>:. The logical unit number starts counting from number 0. For example, if a device has only one logical unit, the <logical_unit_number> specified in this field should be 0. Examples of logical units string name are `ram:0:`, `sdcard:0:`, etc. This function is called several times when a multiple logical unit configuration is created.

Listing - MSC Initialization in the *MSC Configuration* page shows how the latter functions are called during MSC initialization and an example of multiple logical units initialization.

```
USBD_ERR     err;
CPU_INT08U   msc_nbr;
CPU_BOOLEAN  valid;


USBD_MSC_Init(&err);                                                    (1)
if (err != USBD_ERR_NONE){
    return (DEF_FAIL);
}

msc_nbr = USBD_MSC_Add(&err);                                           (2)
if (cfg_hs != USBD_CFG_NBR_NONE){
    valid = USBD_MSC_CfgAdd(msc_nbr,                                    (3)
                            dev_nbr,
                            cfg_hs,
                           &err);
    if (valid != DEF_YES) {
        return (DEF_FAIL);
    }
}

if (cfg_fs != USBD_CFG_NBR_NONE){
    valid = USBD_MSC_CfgAdd(msc_nbr,                                    (4)
                            dev_nbr,
                            cfg_fs,
                           &err);
    if (valid != DEF_YES) {
        return (DEF_FAIL);
    }
}

USBD_MSC_LunAdd((void *)”ram:0:”,                                       (5)
                         msc_nbr,
                        “Micrium”,
                        “MSC LUN 0 RAM”,
                         0x0000,
                         DEF_TRUE,
                        &err);
if (err != USBD_ERR_NONE){
    return (DEF_FAIL);
}

USBD_MSC_LunAdd((void *)”sdcard:0:”,                                    (6)
                         msc_nbr,
                        “Micrium”,
                        “MSC LUN 1 SD”,
                         0x0000,
                         DEF_FALSE,
                        &err);
if (err != USBD_ERR_NONE){
    return (DEF_FAIL);
}

return (DEF_OK);
```

Listing - MSC Initialization

(1) Initialize internal structures and variables used by MSC BOT.

(2) Add a new instance of the MSC.

(3) Check if high speed configuration is active and proceed to add an existing MSC instance to the USB configuration.

(4) Check if full speed configuration is active and proceed to add an existing MSC instance to the USB configuration.

(5) Add a logical unit number to the MSC instance by specifying the type and volume. Note that in this example the <device_driver_name> string is “ram” and <logical_unit_number> string is “0” and the logical unit is read-only (`DEF_TRUE` specified).

(6) Add another logical unit number to the MSC instance by specifying the type and volume. Note that in this example the <device_driver_name> string is “sdcard” and <logical_unit_number> string is “0” and the logical unit is read-write (`DEF_FALSE` specified). When the host will enumerate the mass storage device, this one will report two logical units of different type, one RAM and one SD.

Using the MSC Demo Application

The MSC demo consists of two parts:

- Any file explorer application (Windows, Linux, Mac) from a USB host. For instance, in Windows, mass-storage devices appear as drives in My Computer. From Windows Explorer, users can copy, move, and delete files in the devices.
- The USB Device application on the target board which responds to the request of the host.

µC/USB Device allows the explorer application to access a MSC device such as a NAND/NOR Flash memory, RAM disk, Compact Flash, Secure Digital etc. Once the device is configured for MSC and is connected to the PC host, the operating system will try to load the necessary drivers to manage the communication with the MSC device. For example, Windows loads the built-in drivers disk.sys and PartMgr.sys. You will be able to interact with the device through the explorer application to validate the device stack with MSC.

Note that the demo application provided by Micrium is only an example and is intended to be used as a starting point to develop your own application.

MSC Device Application

On the target side, the user configures the application through the `app_usbd_cfg.h` file. Table - Application Preprocessor Constants in the *Using the MSC Demo Application* page lists a few preprocessor constants that must be defined.

Preprocessor Constants	Description	Default Value
`APP_CFG_USBD_EN`	Enables µC/USB Device in the application.	`DEF_ENABLED`
`APP_CFG_USBD_MSC_EN`	Enables MSC in the application.	`DEF_ENABLED`

Table - Application Preprocessor Constants

If RAMDisk storage is used, ensure that the associated storage layer files are included in the project and configure the following constants located in `app_usbd_cfg.h` and listed in Table - RAM Disk Preprocessor Constants in the *Using the MSC Demo Application* page.

Preprocessor Constants	Description	Default Value
`USBD_RAMDISK_CFG_NBR_UNITS`	Number of RAMDISK units.	1
`USBD_RAMDISK_CFG_BLK_SIZE`	RAMDISK block size.	512
`USBD_RAMDISK_CFG_NBR_BLKS`	RAMDISK number of blocks.	4096
`USBD_RAMDISK_CFG_BASE_ADDR`	RAMDISK base address in memory. This constant is used to define the data area of the RAMDISK. If it is defined with a value different from 0, RAMDISK's data area will be set from this base address directly. If it is equal to 0, RAMDISK's data area will be represented as a table from the program's data area.	0

Table - RAM Disk Preprocessor Constants

If µC/FS storage is used, ensure that the associated µC/FS storage layer files are included in the project and configure the following constants listed in Table - uC/FS Preprocessor Constants in the *Using the MSC Demo Application* page:

Preprocessor Constant	Description	Default Value
APP_CFG_FS_EN	Enables µC/FS in the application	DEF_ENABLED
APP_CFG_FS_DEV_CNT	File system device count.	1
APP_CFG_FS_VOL_CNT	File system volume count.	1
APP_CFG_FS_FILE_CNT	File system file count.	2
APP_CFG_FS_DIR_CNT	File system directory count.	1
APP_CFG_FS_BUF_CNT	File system buffer count.	(2 * APP_CFG_FS_VOL_CNT)
APP_CFG_FS_DEV_DRV_CNT	File system device driver count.	1
APP_CFG_FS_WORKING_DIR_CNT	File system working directory count.	0
APP_CFG_FS_MAX_SEC_SIZE	File system max sector size.	512
APP_CFG_FS_RAM_NBR_SEC	File system number of RAM sectors.	8192
APP_CFG_FS_RAM_SEC_SIZE	File system RAM sector size.	512
APP_CFG_FS_NBR_TEST	File system number of tests.	10
APP_CFG_FS_IDE_EN	Enables IDE device in file system.	DEF_DISABLED
APP_CFG_FS_MSC_EN	Enables MSC device in file system.	DEF_DISABLED
APP_CFG_FS_NOR_EN	Enables NOR device in file system.	DEF_DISABLED
APP_CFG_FS_RAM_EN	Enables RAM device in file system.	DEF_ENABLED
APP_CFG_FS_SD_EN	Enables SD device in file system.	DEF_DISABLED
APP_CFG_FS_SD_CARD_EN	Enables SD card device in file system.	DEF_ENABLED

Table - uC/FS Preprocessor Constants

MSC Host Application

To test the µC/USB-Device stack with MSC, the user can use for instance the Windows Explorer as a USB Host application on a Windows PC.

When the device configured for the MSC demo is connected to the PC, Windows loads the appropriate drivers as shown in Figure - MSC Device Driver Detection on Windows Host in the *Using the MSC Demo Application* page.

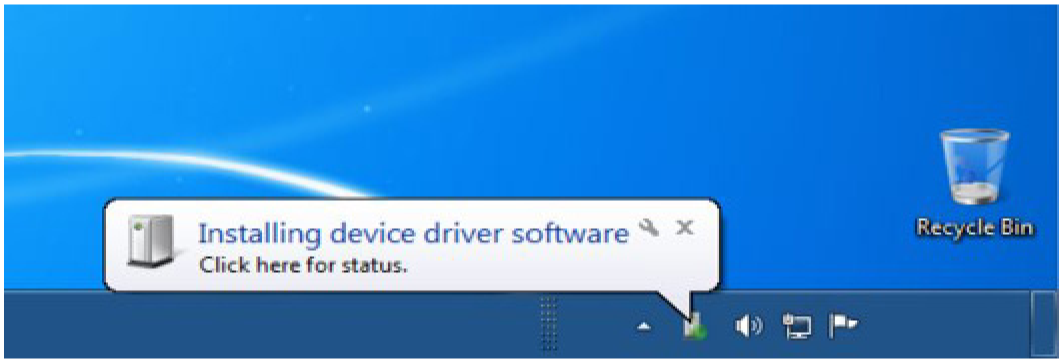


Figure - MSC Device Driver Detection on Windows Host

Open a Windows Explorer and a removable disk appears as shown in Figure - MSC Device on Windows 7 Explorer in the *Using the MSC Demo Application* page. If the MSC demo is modified to configure a mass storage device composed of multiple logical units as shown in Listing - MSC Initialization in the *MSC Configuration* page, Windows Explorer will show a removable disk icon per logical unit.

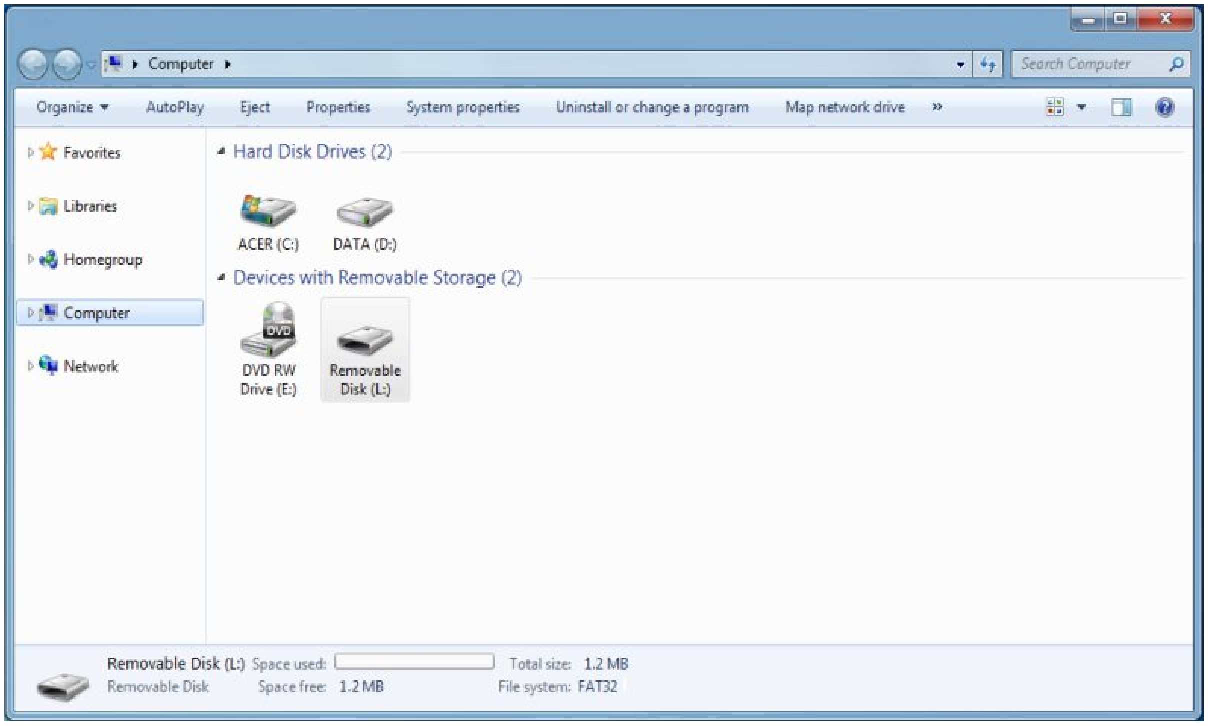


Figure - MSC Device on Windows 7 Explorer

When you open the removable disk, if it is the first time the MSC device is connected to the PC and is not formatted, Windows will ask to format it to handle files on the mass storage. When formatting, choose the File System you want. In embedded systems, the most widespread file system is the FAT.

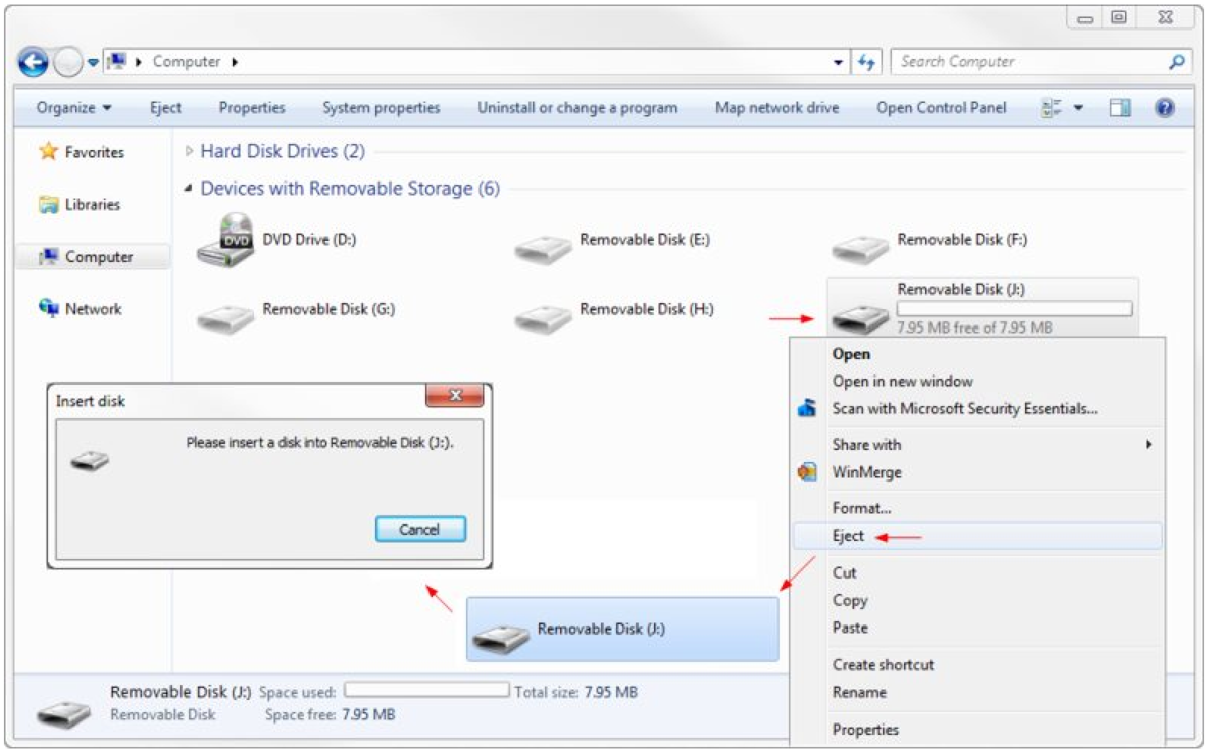
If the mass storage device is a *volatile memory* such as a SDRAM, every time the target board is switched off, the data of the memory is lost, and so is the file system data information. As a result, the next time the target is switched on, the SDRAM is blank and reconnecting the mass storage to the PC, you will have to format again the mass storage device.

Once the device is correctly formatted, you are ready to test the MSC demo. Below are a few examples of what you can do:

- You can create one or more text files.
- You can write data in these files.
- You can open them to read the content of the files.
- You can copy/paste data.
- You can delete one or more files.

All of these actions will generate SCSI commands to write and read the mass storage device.

The MSC class supports the removable storage eject option offered by any major operating systems. Figure - Windows Removable Storage Eject Option Example in the *Using the MSC Demo Application* page shows an example of Eject option available in Windows Explorer. When you right-click on the removable disk, you can choose the *Eject* option. Eject option will send to the mass storage device some special SCSI commands. The mass storage device will stop the access to the storage. Hence, Windows will modify the removable disk icon by removing the size information. If you double-click on the icon after the eject operation, Windows will display a message saying that no disk is inserted. After an eject operation, you cannot reactivate the removable media. The only way is to disconnect the device and reconnect it so that Windows will re-enumerate it and refresh the Windows explorer's content.



Please insert a disk into Removable Disk (J:).

Figure - Windows Removable Storage Eject Option Example

Porting MSC to a Storage Layer

The storage layer port must implement the API functions summarized in Table - Storage API Functions in the *Porting MSC to a Storage Layer* page. You can start by referencing to the storage port template located under:

```
Micrium\Software\uC-USB-Device-V4\Class\MSC\Storage\Template
```

You can also refer to the RAMDisk storage and µC/FS storage located in `Micrium\Software\uC-USB-Device-V4\Class\MSC\Storage\` for a more detailed example of storage layer implementation.

Please refer to the MSC Storage Layer Functions Reference for a full description of the storage layer API.

Function Name	Operation
`USBD_StorageInit()`	Initializes internal tables used by the storage layer.
`USBD_StorageAdd()`	Initializes storage medium.
`USBD_StorageCapacityGet()`	Gets the storage medium's capacity.
`USBD_StorageRd()`	Reads data from the storage medium.
`USBD_StorageWr()`	Writes data to the storage medium.
`USBD_StorageStatusGet()`	Gets storage medium's status. If the storage medium is a removable device such as an SD/MMC card, this function will return if the storage is inserted or removed.
`USBD_StorageLock()`	Locks access to the storage medium.
`USBD_StorageUnlock()`	Unlocks access to the storage medium.
`USBD_StorageRefreshTaskHandler()`	Checks the removable media presence status, that is insertion/removal detection. Defined only for the µC/FS storage layer.

Table - Storage API Functions

Porting MSC to an RTOS

The RTOS layer must implement the API functions listed in Table - RTOS API Functions in the *Porting MSC to an RTOS* page. You can start by referencing the RTOS port template located under:

```
Micrium\Software\uC-USB-Device-V4\Class\MSC\OS\Template
```

Please refer to the MSC OS Functions Reference page for a full API description.

Function	Operation
`USBD_MSC_OS_Init`	Initializes MSC OS interface. This function will create both signals (semaphores) for communication and enumeration processes. Furthermore, this function will create the MSC task used for the MSC protocol. If µC/FS storage layer is used with removable media, the Refresh task will be created.
`USBD_MSC_OS_CommSignalPost`	Posts a semaphore used for MSC communication.
`USBD_MSC_OS_CommSignalPend`	Waits on a semaphore to become available for MSC communication.
`USBD_MSC_OS_CommSignalDel`	Deletes a semaphore if no tasks are waiting for it for MSC communication.
`USBD_MSC_OS_EnumSignalPost`	Posts a semaphore used for MSC enumeration process.
`USBD_MSC_OS_EnumSignalPend`	Waits for a semaphore to become available for MSC enumeration process.
`USBD_MSC_OS_Task`	Task processing the MSC protocol. Refer to the Mass Storage Task Handler section for more details about this task.
`USBD_MSC_OS_RefreshTask`	Task responsible for removable media insertion/removal detection. This task is only present when µC/FS storage layer is used with removable media.

Table - RTOS API Functions

Personal Healthcare Device Class

This section describes the Personal Healthcare Device Class (PHDC) supported by C/USB-Device. The implementation offered refers to the following USB-IF specification:

- *USB Device Class Definition for Personal Healthcare Devices, release 1.0, Nov. 8 2007.*

PHDC allows you to build USB devices that are meant to be used to monitor and improve personal healthcare. Lots of modern personal healthcare devices have arrived on the market in recent years. Glucose meter, pulse oximeter and blood-pressure monitor are some examples. A characteristic of these devices is that they can be connected to a computer for playback, live monitoring or configuration. One of the typical ways to connect these devices to a computer is by using a USB connection, and that’s why PHDC has been developed.

Although PHDC is a standard, most modern Operating Systems (OS) do not provide any specific driver for this class. When working with Microsoft Windows®, developers can use the WinUsb driver provided by Microsoft to create their own driver. The Continua Health Alliance also provides an example of a PHDC driver based on libusb (an open source USB library, for more information, see `http://www.libusb.org/`). This example driver is part of the Vendor Assisted Source-Code (VASC).

PHDC Overview

Data Characteristics

Personal healthcare devices, due to their nature, may need to send data in 3 different ways:

- Episodic: data is sent sporadically each time the user accomplishes a specific action.
- Store and forward: data is collected and stored on the device while it is not connected. The data is then forwarded to the host once it is connected.
- Continuous: data is sent continuously to the host for continuous monitoring.

Considering these needs, data transfers will be defined in terms of latency and reliability. PHDC defines three levels of reliability and four levels of latency:

- Reliability: Good, better and best.
- Latency: Very-high, high, medium and low.

For example, a device that sends continuous data for monitoring will send them as low latency and good reliability.

PHDC does not support all latency/reliability combinations. Here is a list of supported combinations:

- Low latency, good reliability.
- Medium latency, good reliability.
- Medium latency, better reliability.
- Medium latency, best reliability.
- High latency, best reliability.
- Very high latency, best reliability.

These combinations are called quality of service (QoS).

QoS (Latency/reliability)	Latency	Raw info rate	Transfer direction(s)	Typical use
Low / good	< 20ms	50 bits/sec to 1.2M bits/sec	IN	Real-time monitoring, with fast analog sampling rate.
Medium / good	< 200ms	50 bits/sec to 1.2M bits/s	IN	
Medium / better	< 200ms	10s of byte range	IN	Data from measured parameter collected off-line and replayed or sent real-time.
Medium / best	< 200ms	10s of byte range	IN, OUT	Events, notifications, request, control and status of physiological and equipment functionality.
High / best	< 2s	10s of byte range	IN, OUT	Physiological and equipment alarms.
Very high / best	< 20s	10s of byte range to gigabytes of data	IN, OUT	Transfer reports, histories or off-line collection of data.

Table - QoS Levels Description

Transfers from a PHDC device will also contain a preamble, in which there is the possibility to include opaque data. Opaque data is data that should not be treated as actual data, but instead acts as a header, allowing the receiving host application to know what type of data it receives, for example. See Table - Metadata Preamble in the *PHDC Overview* page for more details about the content of a preamble.

Operational Model

The requirements for data transfer QoS in personal healthcare devices can be accomplished by PHDC using bulk endpoints and, optionally, an interrupt endpoint. Table - Endpoint - QoS Mapping in the *PHDC Overview* page and Figure - QoS - Endpoint Mapping in the *PHDC Overview* page show the mapping between QoS and endpoint types.

Endpoint	Usage
Bulk OUT	All QoS host to device data transfers.
Bulk IN	Very high, high and medium latency device to host data transfers.
Interrupt IN	Low latency device to host data transfers.

Table - Endpoint - QoS Mapping

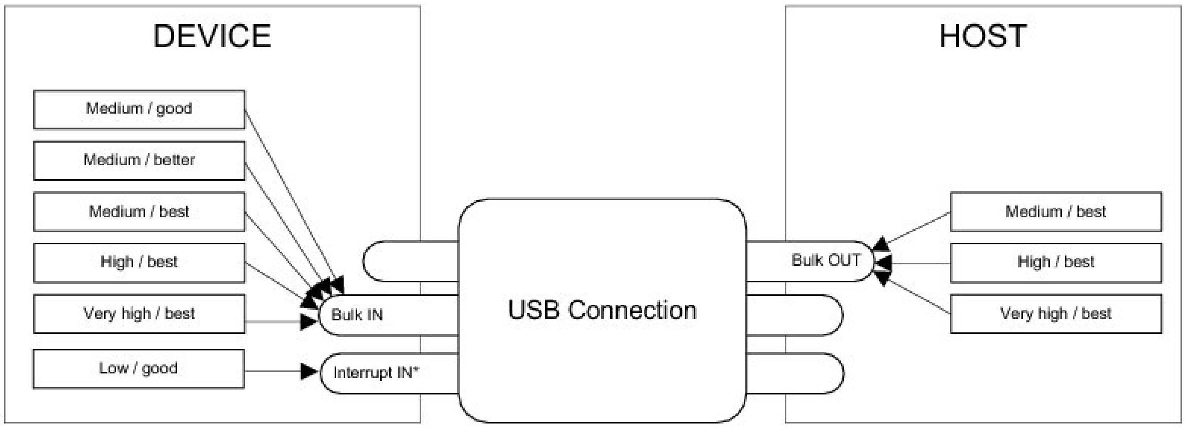


Figure - QoS - Endpoint Mapping

PHDC does not define a protocol for data and messaging. It is only intended to be used as a communication layer. Developers can use either data and messaging protocol defined in ISO/IEEE 11073-20601 base protocol or a vendor-defined protocol. Figure - Personal Healthcare Device Software Layers in the *PHDC Overview* page shows the different software layers needed in a personal healthcare device.

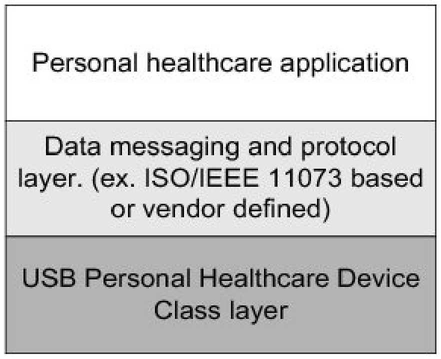

Personal healthcare application
Data messaging and protocol layer. (ex. ISO/IEEE 11073 based or vendor defined)
USB Personal Healthcare Device Class layer

Figure - Personal Healthcare Device Software Layers

Since transfers having different QoS will have to share a single bulk endpoint, host and device need a way to inform each other what is the QoS of the current transfer. A metadata message preamble will then be sent before a single or a group of regular data transfers. This preamble will contain the information listed in Table - Metadata Preamble in the *PHDC Overview* page.

Offset	Field	Size (bytes)	Description
0	`aSignature`	16	Constant used to verify preamble validity. Always set to “PhdcQoSSignature” string.
16	`bNumTransfers`	1	Count of following transfers to which QoS setting applies.
17	`bQoSEncodingVersion`	1	QoS information encoding version. Should be 0x01.
18	`bmLatencyReliability`	1	Bitmap that refers to latency / reliability bin for data.
19	`bOpaqueDataSize`	1	Length, in bytes, of opaque data.
20	`bOpaqueData`	[0 .. `MaxPacketSize` - 21]	Optional data usually application specific that is opaque to the class.

Table - Metadata Preamble

PHDC Configuration

General Configuration

Some constants are available to customize the class. These constants are located in the `usbd_cfg.h` file. Table - Configuration Constants Summary in the *PHDC Configuration* page shows a description of each of them.

Constant	Description	Possible Values
`USBD_PHDC_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances. Unless you plan on having multiple configuration or interfaces using different class instances, this can be set to **1**.	From 1 to 254. Default value is **1**.
`USBD_PHDC_CFG_MAX_NBR_CFG`	Configures the maximum number of configuration in which PHDC is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed. Default value is **2**.	From 1 (low- and full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_PHDC_CFG_DATA_OPAQUE_MAX_LEN`	Maximum length in octets that opaque data can be.	Equal or less than MaxPacketSize - 21. Default value is **43**.
`USBD_PHDC_OS_CFG_SCHED_EN`	If using µC/OS-II or µC/OS-III RTOS port, enable or disable the scheduler feature. You should set it to `DEF_DISABLED` if the device only uses one QoS level to send data, for instance. (See the PHDC RTOS QoS-based scheduler page). If you set `USBD_PHDC_OS_CFG_SCHED_EN` to `DEF_ENABLED` and you use a µC/OS-II or µC/OS-III RTOS port, PHDC will need an internal task for the scheduling operations. There are two application specific configurations that must be set in this case. They should be defined in the `app_cfg.h` file. If you set this constant to `DEF_ENABLED`, you *must* ensure that the scheduler's task has a lower priority (i.e., higher priority value) than any task that can write PHDC data.	**`DEF_ENABLED`** or `DEF_DISABLED`

Table - Configuration Constants Summary

If you set `USBD_PHDC_OS_CFG_SCHED_EN` to `DEF_ENABLED` and you use a µC/OS-II or µC/OS-III RTOS port, PHDC will need an internal task for the scheduling operations. There are two application specific configurations that must be set in this case. They should be defined in the `app_cfg.h` file. Table - Application-Specific Configuration Constants in the *PHDC Configuration* page describes these configurations.

Constant	Description	Possible Values
`USBD_PHDC_OS_CFG_SCHED_TASK_PRIO`	QoS based scheduler's task priority. You *must* ensure that the scheduler's task has a lower priority (i.e. higher priority value) than any task writing PHDC data.	From the lowest to the highest priority supported by the OS used.
`USBD_PHDC_OS_CFG_SCHED_TASK_STK_SIZE`	QoS based scheduler's task stack size. The required size of the stack can greatly vary depending on the OS used, the CPU architecture, the type of application, etc. Refer to the documentation of the OS for more details about tasks and stack size calculation.	From the minimal to the maximal stack size supported by the OS used. Default value is **512**.

Table - Application-Specific Configuration Constants

Class Instance Configuration

Before starting the communication phase, your application needs to initialize and configure the class to suit its needs. Table - PHDC Initialization API Summary in the *PHDC Configuration* page summarizes the initialization functions provided by the PHDC implementation. For a complete API reference, see the PHDC Functions reference.

Function name	Operation
`USBD_PHDC_Init()`	Initializes PHDC internal structures and variables.
`USBD_PHDC_Add()`	Adds a new instance of PHDC.
`USBD_PHDC_RdCfg()`	Configures read communication pipe parameters.
`USBD_PHDC_WrCfg()`	Configures write communication pipe parameters.
`USBD_PHDC_11073_ExtCfg()`	Configures IEEE 11073 function extension(s).
`USBD_PHDC_CfgAdd()`	Adds PHDC instance into USB device configuration.

Table - PHDC Initialization API Summary

You need to follow these steps to successfully initialize PHDC:

1. Call `USBD_PHDC_Init()`
   This is the first function you should call, and you should do it only once, even if you use multiple class instances. This function will initialize all internal structures and variables that the class will need. It will also initialize the real-time operating system (RTOS) layer.

2. Call `USBD_PHDC_Add()`
   This function will allocate a PHDC instance. This call will also let you determine if the PHDC instance is capable of sending / receiving the metadata message preamble and if it uses a vendor-defined or ISO/IEEE-11073 based data and messaging protocol.
   Another parameter of this function lets you specify a callback function that the class will call when the host enables / disables metadata message preambles. This is useful for the application as the behavior in communication will differ depending on the metadata message preamble state.
   If your application needs to send low latency / good reliability data, the class will need to allocate an interrupt endpoint. The endpoint's interval will be specified in this call as well.

3. Call `USBD_PHDC_RdCfg()` and `USBD_PHDC_WrCfg()`
   The next step is to call `USBD_PHDC_RdCfg()` and `USBD_PHDC_WrCfg()`. These functions will let you set the latency / reliability bins that the communication pipe will carry. Bins are listed in Table - Listing of QoS Bins in the *PHDC Configuration* page. It will also be used to specify opaque data to send within extra endpoint metadata descriptors (see "USB Device Class Definition for Personal Healthcare Devices", Release 1.0, Section 5 for more details on PHDC extra descriptors).

Name	Description
`USBD_PHDC_LATENCY_VERYHIGH_RELY_BEST`	Very-high latency, best reliability.
`USBD_PHDC_LATENCY_HIGH_RELY_BEST`	High latency, best reliability.
`USBD_PHDC_LATENCY_MEDIUM_RELY_BEST`	Medium latency, best reliability.
`USBD_PHDC_LATENCY_MEDIUM_RELY_BETTER`	Medium latency, better reliability.
`USBD_PHDC_LATENCY_MEDIUM_RELY_GOOD`	Medium latency, good reliability.
`USBD_PHDC_LATENCY_LOW_RELY_GOOD`	Low latency, good reliability.

Table - Listing of QoS Bins

4. Call `USBD_PHDC_11073_ExtCfg()` (optional)
   If the PHDC instance uses ISO/IEEE 11073-based data and messaging protocol, a call

to this function will let you configure the device specialization code(s).

5. Call `USBD_PHDC_CfgAdd()`

Finally, once the class instance is correctly configured and initialized, you will need to add it to a USB configuration. This is done by calling `USBD_PHDC_CfgAdd()`.

Listing - PHDC Instance Initialization and Configuration Example in the *PHDC Configuration* page shows an example of initialization and configuration of a PHDC instance. If you need more than one class instance of PHDC for your application, refer to the Class Instance Concept page for generic examples of how to build your device.

```
CPU_BOOLEAN  App_USBD_PHDC_Init(CPU_INT08U  dev_nbr,
                                CPU_INT08U  cfg_hs,
                                CPU_INT08U  cfg_fs)
{
    USBD_ERR    err;
    CPU_INT08U  class_nbr;


    USBD_PHDC_Init(&err);                                                     (1)
    class_nbr = USBD_PHDC_Add(DEF_YES,                                        (2)
                              DEF_YES,
                              App_USBD_PHDC_SetPreambleEn,
                              10,
                             &err);

    latency_rely_flags = USBD_PHDC_LATENCY_VERYHIGH_RELY_BEST |
                         USBD_PHDC_LATENCY_HIGH_RELY_BEST     |
                         USBD_PHDC_LATENCY_MEDIUM_RELY_BEST;
    USBD_PHDC_RdCfg(class_nbr,                                                (3)
                    latency_rely_flags,
                    opaque_data_rx,
                    sizeof(opaque_data_rx),
                   &err);
    USBD_PHDC_WrCfg(class_nbr,                                                (3)
                    USBD_PHDC_LATENCY_VERYHIGH_RELY_BEST,
                    opaque_data_tx,
                    sizeof(opaque_data_tx),
                   &err);

    USBD_PHDC_11073_ExtCfg(class_nbr, dev_specialization, 1, &err);           (4)
    valid_cfg_hs = USBD_PHDC_CfgAdd(class_nbr, dev_nbr, cfg_hs, &err);        (5)
    valid_cfg_fs = USBD_PHDC_CfgAdd(class_nbr, dev_nbr, cfg_fs, &err);        (6)
}
```

Listing - PHDC Instance Initialization and Configuration Example

(1) Initialize PHDC internal members and variables.

(2) Create a PHDC instance, this instance support preambles and ISO/IEEE 11073 based

data and messaging protocol.

(3) Configure read and write pipes with correct QoS and opaque data.

(4) Add ISO/IEEE 11073 device specialization to PHDC instance.

(5) Add class instance to high-speed configuration.

(6) Add class instance to full-speed configuration.

PHDC Class Instance Communication

Now that the class instance has been correctly initialized, it's time to exchange data. PHDC offers 4 functions to do so. Table - PHDC Communication API Summary in the *PHDC Class Instance Communication* page summarizes the communication functions provided by the PHDC implementation. See the PHDC API Reference for a complete API reference.

Function name	Operation
`USBD_PHDC_PreambleRd()`	Reads metadata preamble.
`USBD_PHDC_Rd()`	Reads PHDC data.
`USBD_PHDC_PreambleWr()`	Writes metadata preamble.
`USBD_PHDC_Wr()`	Writes PHDC data.

Table - PHDC Communication API Summary

With Metadata Preamble

Via the preamble enabled callback, the application will be notified once the host enables the metadata preamble. If metadata preambles are enabled, you should use the following procedure to perform a read:

- Call `USBD_PHDC_PreambleRd()`. Device expects metadata preamble from the host. This function will return opaque data and the number of incoming transfers that the host specified. Note that if the host disables preamble while the application is pending on that function, it will immediately return with error "`USBD_ERR_OS_ABORT`".

- Call `USBD_PHDC_Rd()` a number of times corresponding to the number of incoming transfers returned by `USBD_PHDC_PreambleRd()`. The application must ensure that the buffer provided to the function is large enough to accommodate all the data. Otherwise, synchronization issues might happen. Note that if the host enables preamble while the application is pending on that function, it will immediately return with error "`USBD_ERR_OS_ABORT`".

```
CPU_INT16U  App_USBD_PHDC_Rd(CPU_INT08U   class_nbr,
                             CPU_INT08U  *p_data_opaque_buf
                             CPU_INT08U  *p_data_opaque_len,
                             CPU_INT08U  *p_buf,
                             USBD_ERR    *p_err)
{
    CPU_INT08U  nbr_xfer;
    CPU_INT16U  xfer_len;
    CPU_INT08U  i;


   *p_data_opaque_len = USBD_PHDC_PreambleRd(        class_nbr,               (1)
                                             (void *)p_data_opaque_buf,       (2)
                                                     USBD_PHDC_CFG_DATA_OPAQUE_MAX_LEN,
                                                    &nbr_xfer,                (3)
                                                     0,                       (4)
                                                     p_err);

    for (i = 0u; i < nbr_xfer; i++) {                                         (5)
        xfer_len = USBD_PHDC_Rd(        class_nbr,
                                (void *)p_buf,                                (6)
                                        APP_USBD_PHDC_ITEM_DATA_LEN_MAX,
                                        0,                                    (4)
                                        p_err);

        /* Handle received data. */
    }

    return (xfer_len);
}
```

Listing - PHDC Read Procedure

(1) The class instance number obtained with `USBD_PHDC_Add()` will serve internally to the PHDC class to route the data to the proper endpoints.

(2) Buffer that will contain opaque data. The application must ensure that the buffer provided is large enough to accommodate all the data. Otherwise, synchronization issues might happen.

(3) Variable that will contain the number of following transfers to which this preamble applies.

(4) In order to avoid an infinite blocking situation, a timeout expressed in milliseconds can be specified. A value of ‘0’ makes the application task wait forever.

(5) Read all the USB transfers to which the preamble applies.

(6) Buffer that will contain the data. The application must ensure that the buffer provided is

large enough to accommodate all the data. Otherwise, synchronization issues might happen.

You should use the following procedure to perform a write:

- Call `USBD_PHDC_PreambleWr()`. The host expects metadata preamble from the device. The application will have to specify opaque data, transfer's QoS (see Listing - Listing of QoS Bins in the *PHDC Configuration* page), and a number of following transfers to which the selected QoS applies.

- Call `USBD_PHDC_Wr()` a number of times corresponding to the number of transfers following the preamble.

```
CPU_INT16U  App_USBD_PHDC_Wr(CPU_INT08U           class_nbr,
                             LATENCY_RELY_FLAGS   latency_rely,
                             CPU_INT08U           nbr_xfer,
                             CPU_INT08U          *p_data_opaque_buf
                             CPU_INT08U           data_opaque_buf_len,
                             CPU_INT08U          *p_buf,
                             CPU_INT08U           buf_len,
                             USBD_ERR            *p_err)
{
    CPU_INT08U  i;


    (void)USBD_PHDC_PreambleWr(        class_nbr,                             (1)
                               (void *)p_data_opaque_buf,                     (2)
                                       data_opaque_buf_len,
                                       latency_rely,                          (3)
                                       nbr_xfer,                              (4)
                                       0,                                     (5)
                                       p_err);

    for (i = 0u; i < nbr_xfer; i++) {                                         (6)
        /* Prepare data to send. */

        xfer_len = USBD_PHDC_Wr(        class_nbr,                            (1)
                                (void *)p_buf,                                (7)
                                        buf_len,
                                        latency_rely,                         (3)
                                        0,
                                        p_err);
    }
}
```

Listing - PHDC Write Procedure

(1) The class instance number obtained with `USBD_PHDC_Add()` will serve internally to the PHDC class to route the data to the proper endpoints.

(2) Buffer that contains opaque data.

(3) Latency / reliability (QoS) of the following transfer(s).

(4) Variable that contains the number of following transfers to which this preamble will apply.

(5) In order to avoid an infinite blocking situation, a timeout expressed in milliseconds can be specified. A value of ‘0’ makes the application task wait forever.

(6) Write all the USB transfers to which the preamble will apply.

(7) Buffer that contains the data.

Without Metadata Preamble

If the device does not support metadata preamble or if it supports them but it has not been enabled by the host, you should not call `USBD_PHDC_PreambleRd()` and `USBD_PHDC_PreambleWr()`.

PHDC RTOS QoS-based scheduler

Since it is possible to send data with different QoS using a single bulk endpoint, you might want to prioritize the transfers by their QoS latency (medium latency transfers processed before high latency transfers, for instance). This kind of prioritization is implemented inside PHDC µC/OS-II and µC/OS-III RTOS layer. Table - QoS Based Scheduler Priority Values in the *PHDC RTOS QoS-based scheduler* page shows the priority value associated with each QoS latency (the lowest priority value will be treated first).

QoS latency	QoS based scheduler associated priority
Very high latency	3
High latency	2
Medium latency	1

Table - QoS Based Scheduler Priority Values

For instance, let’s say that your application has 3 tasks. Task A has an OS priority of 1, task B has an OS priority of 2 and task C has an OS priority of 3. Note that a low priority number indicates a high priority task. Now say that all 3 tasks want to write PHDC data of different QoS latency. Task A wants to write data that can have very high latency, task B wants to write data that can have medium latency, and finally, task C wants to write data that can have high latency. Table - QoS-Based Scheduling Example in the *PHDC RTOS QoS-based scheduler* page shows a summary of the tasks involved in this example.

Task	QoS latency of data to write	OS priority	QoS priority of data to write
A	Very high	1	3
B	Medium	2	1
C	High	3	2

Table - QoS-Based Scheduling Example

If no QoS based priority management is implemented, the OS will then resume the tasks in the order of their OS priority. In this example, the task that has the higher OS priority, A, will be resumed first. However, that task wants to write data that can have very high latency (QoS priority of 3). A better choice would be to resume task B first, which wants to send data that can have medium latency (QoS priority of 1). Figure - Task Execution Order, Without QoS

Based Scheduling in the *PHDC RTOS QoS-based scheduler* page and Figure - Task Execution Order, with QoS Based Scheduling in the *PHDC RTOS QoS-based scheduler* page represent this example without and with a QoS-based scheduler, respectively.

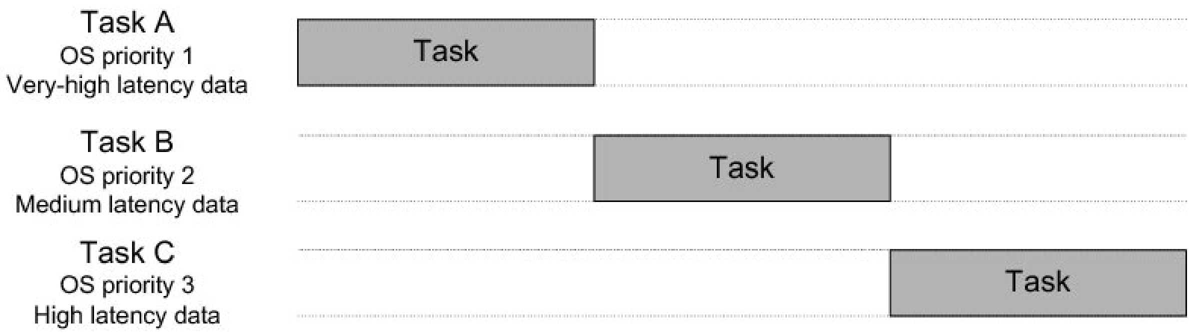


Figure - Task Execution Order, Without QoS Based Scheduling

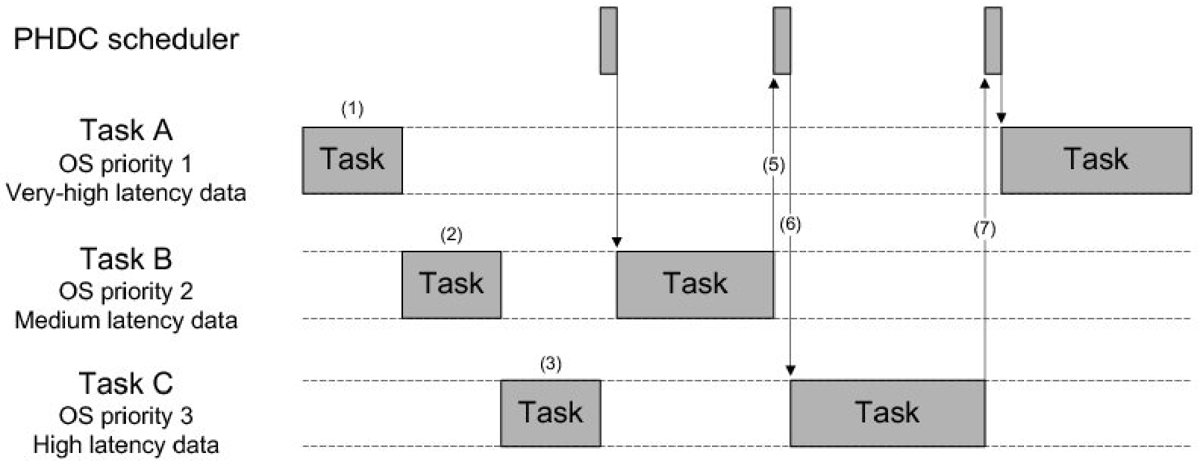


Figure - Task Execution Order, with QoS Based Scheduling

(1)

(2)

(3) A task currently holds the lock on the write bulk endpoint, task A, B and C are added to the wait list until the lock is released.

(4) The lock has been released. The QoS based scheduler's task is resumed, and finds the task that should be resumed first (according to the QoS of the data it wants to send).

Task B is resumed.

(5) Task B completes its execution and releases the lock on the pipe. This resumes the scheduler's task.

(6) Again, the QoS based scheduler finds the next task that should be resumed. Task C is resumed.

(7) Task C has completed its execution and releases the lock. Scheduler task is resumed and determines that task A is the next one to be resumed.

The QoS-based scheduler is implemented in the RTOS layer. Three functions are involved in the execution of the scheduler.

Function name	Called by	Operation
`USBD_PHDC_OS_WrBulkLock()`	`USBD_PHDC_Wr()` or `USBD_PHDC_PreambleWr()`, depending if preambles are enabled or not.	Locks write bulk pipe.
`USBD_PHDC_OS_WrBulkUnlock()`	`USBD_PHDC_Wr()`.	Unlocks write bulk pipe.
`USBD_PHDC_OS_WrBulkSchedTask()`	N/A.	Determines next task to resume.

Table - QoS-Based Scheduler API Summary

The pseudocode for these three functions is shown in the three following listings.

```
void  USBD_PHDC_OS_WrBulkLock (CPU_INT08U   class_nbr,
                               CPU_INT08U   prio,
                               CPU_INT16U   timeout_ms,
                               USBD_ERR    *p_err)
{
    Increment transfer count of given priority (QoS);
    Post scheduler lock semaphore;
    Pend on priority specific semaphore;
    Decrement transfer count of given priority (QoS);
}
```

Listing - Pseudocode for USBD_PHDC_OS_WrBulkLock()

```
void  USBD_PHDC_OS_WrBulkUnlock (CPU_INT08U  class_nbr)
{
    Post scheduler release semaphore;
}
```

Listing - Pseudocode for USBD_PHDC_OS_WrBulkUnlock()

```
static  void  USBD_PHDC_OS_WrBulkSchedTask (void *p_arg)
{
    Pend on scheduler lock semaphore;

    Get next highest QoS ready;
    PostSem(SemList[QoS]);

    Pend on scheduler release semaphore;
}
```

Listing - Pseudocode for QoS-Based Scheduler’s Task

Using the PHDC Demo Application

Micrium provides a demo application that lets you test and evaluate the class implementation. Source files are provided for the device (for C/OS-II and C/OS-III only). Executable and source files are provided for the host (Windows only).

Note that the demo application provided by Micriµm is only an example and is intended to be used as a starting point to develop your own application.

Set Up the PHDC Demo Application

On the target side, you should compile the application file, `app_usbd_phdc.c` , with your project. This file is located in the following folder:

```
\Micrium\Software\uC-USB-Device-V4\App\Device\
```

The demo application allows you to send and receive different QoS levels for data transfers. All transfers sent by the host application is received using a single receive task. While all transfers sent by the device are handled using one or several transmit tasks assuming one QoS level per transmit task. You can have several tasks transmitting data with the same QoS. When several transmit tasks are used, you may enable the RTOS QoS-based scheduler to prioritize the transfers by their QoS latency.

Several constants are available to customize the demo application on both device and host (Windows) side. Table - Device Side Demo Application's Configuration Constants in the *Using the PHDC Demo Application* page describe device side constants that are located in the `app_cfg.h` or `app_usbd_cfg.h` file. Table - Host Side (Windows) Demo Application's Configuration Constants in the *Using the PHDC Demo Application* page describe host side constants that are located in the `app_phdc.c` file.

Constant	Description	File
`APP_CFG_USBD_PHDC_EN`	Set to `DEF_ENABLED` to enable the demo application.	`app_usbd_cfg.h`
`APP_CFG_USBD_PHDC_ITEM_DATA_LEN_MAX`	Set this constant to the maximum number of bytes that can be transferred as data. Must be >= 5.	`app_usbd_cfg.h`
`APP_CFG_USBD_PHDC_ITEM_NBR_MAX`	Set this constant to the maximum number of items that the application should support. Must be >= 1.	`app_usbd_cfg.h`
`APP_CFG_USBD_PHDC_MAX_NBR_TASKS`	Set this constant to the number of transmit tasks needed to handle all the QoS levels. Must be >= 1. Each created task will send data attached to one specific QoS level. If this constant is greater than one, usually `USBD_PHDC_OS_CFG_SCHED_EN` is set to `DEF_ENABLED`. Otherwise, `USBD_PHDC_OS_CFG_SCHED_EN` can be set to `DEF_DISABLED`.	`app_usbd_cfg.h`
`APP_CFG_USBD_PHDC_TX_COMM_TASK_PRIO`	Priority of the write task.	`app_cfg.h`
`APP_CFG_USBD_PHDC_RX_COMM_TASK_PRIO`	Priority of the read task.	`app_cfg.h`
`APP_CFG_USBD_PHDC_TASK_STK_SIZE`	Stack size of both read and write tasks. Default value is 512.	`app_cfg.h`

Table - Device Side Demo Application's Configuration Constants

Constant	Description
`APP_ITEM_DATA_LEN_MAX`	Set this constant to the maximum number of bytes that can be transferred as data. Must be >= 5.
`APP_ITEM_DATA_OPAQUE_LEN_MAX`	Set this constant to the maximum number of bytes that can be transferred as opaque data. Must be <= (*MaxPacketSize* - 21).
`APP_ITEM_NBR_MAX`	Set this constant to the maximum number of items that the application should support. Must be >= 1.
`APP_STAT_COMP_PERIOD`	Set this constant to the period (in ms) on which the statistic of each transfer (mean and standard deviation) should be computed.
`APP_ITEM_PERIOD_MIN`	Set this constant to the minimum period (in ms) that a user can specify for an item.
`APP_ITEM_PERIOD_MAX`	Set this constant to the maximum period (in ms) that a user can specify for an item.
`APP_ITEM_PERIOD_MULTIPLE`	Set this constant to a multiple (in ms) that periodicity of items specified by the user must comply.

Table - Host Side (Windows) Demo Application's Configuration Constants

Since Microsoft does not provide any specific driver for PHDC, you will have to indicate to windows which driver to load using an INF file. The INF file will ask Windows to load the WinUSB generic driver (provided by Microsoft). The application uses the USBDev_API, which is a wrapper of the WinUSB driver (refer to the USBDev_API page).

Windows will ask for the INF file (refer to the About INF Files section) the first time the device will be plugged-in. It is located in the following folder:

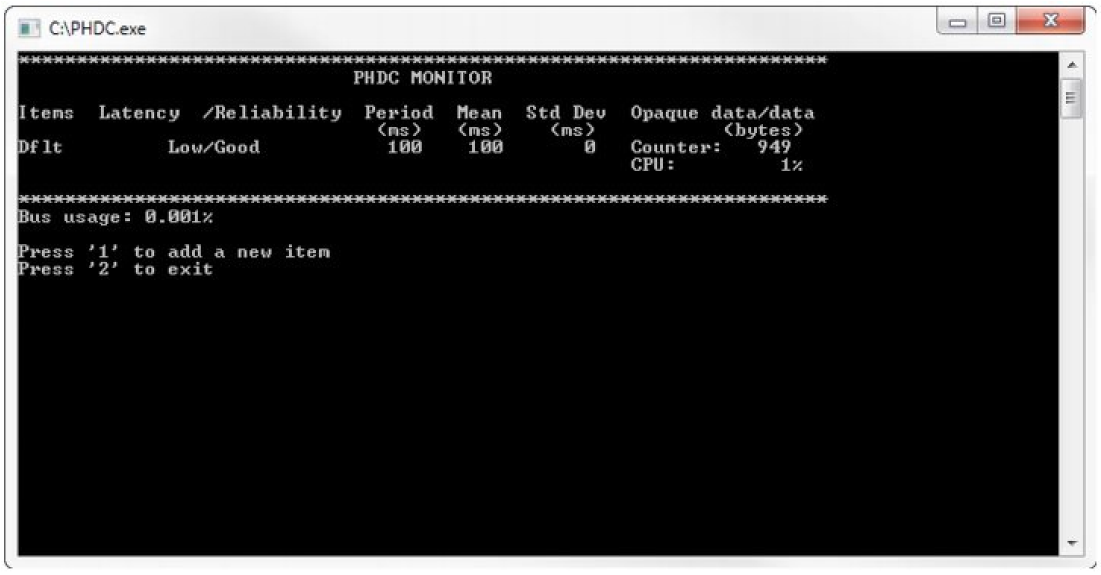
```
\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\PHDC\INF
```

Once the driver is successfully loaded, the Windows host application is ready to be launched. The executable is located in the following folder:

```
\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\PHDC\Visual Studio 2010\exe
```

Running the PHDC Demo Application

In this demo application, you can ask the device to continuously send data of different QoS level and using a given periodicity. Each requested transfer is called an "item". Using the monitor, you can see each transfer's average periodicity and standard deviation. The monitor will also show the data and opaque data that you specified. At startup, the application will always send a default item with a periodicity of 100 ms. This item will send the device CPU usage and the value of a counter that is incremented each time the item is sent. The default item uses low latency / good reliability as QoS. Figure - Demo Application at Startup in the *Using the PHDC Demo Application* page shows the demo application at startup.



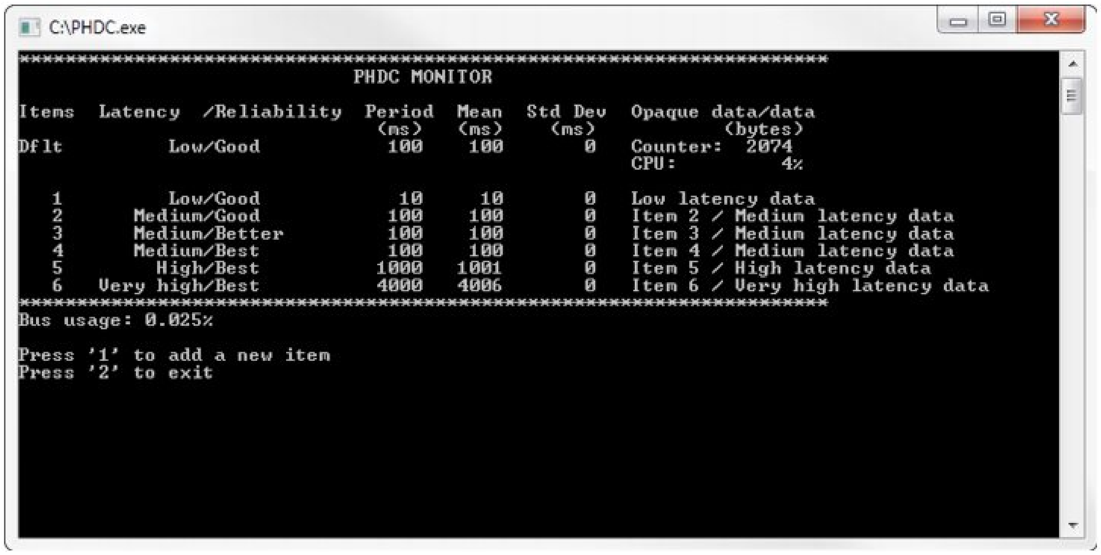
```
**********************************************************************
                             PHDC MONITOR

Items   Latency  /Reliability  Period  Mean  Std Dev  Opaque data/data
                                (ms)   (ms)   (ms)           (bytes)
Dflt          Low/Good          100    100      0     Counter:   949
                                                      CPU:        1%

**********************************************************************
Bus usage: 0.001%

Press '1' to add a new item
Press '2' to exit
```

Figure - Demo Application at Startup

At this point, you have the possibility to add a new item by pressing 1. You will be prompted to specify the following values:

- Periodicity of the transfer: the period at which the transfer will attempt to occur.
- QoS (Latency / reliability) of the transfer: the type of QoS desired for this transfer.
- Opaque data (if QoS is not low latency / good reliability): the opaque data that will be included in this transfer.
- Data: the actual data that will be transferred.

Figure - Demo Application with Five Items Added in the *Using the PHDC Demo Application* page shows the demo application with a few items added.



```
**********************************************************************
                             PHDC MONITOR

Items  Latency  /Reliability  Period  Mean  Std Dev  Opaque data/data
                               (ms)   (ms)   (ms)           (bytes)
Dflt         Low/Good          100    100       0    Counter:  2074
                                                     CPU:         4%

   1         Low/Good           10     10       0    Low latency data
   2      Medium/Good          100    100       0    Item 2 / Medium latency data
   3      Medium/Better        100    100       0    Item 3 / Medium latency data
   4      Medium/Best          100    100       0    Item 4 / Medium latency data
   5        High/Best         1000   1001       0    Item 5 / High latency data
   6   Very high/Best         4000   4006       0    Item 6 / Very high latency data
**********************************************************************
Bus usage: 0.025%

Press '1' to add a new item
Press '2' to exit
```

Figure - Demo Application with Five Items Added

Once an item has been added, the application provides statistics about every transfer. From left to right, there is the item’s number, the type of QoS, the ideal period, the mean period value, the standard deviation value and the opaque data/data. The mean and standard deviation values are calculated by the host application, based on a sampling of the actual period value obtained for every single transfer.

Porting PHDC to an RTOS

Since PHDC communication functions can be called from different tasks at application level, there is a need to protect the resources they use (in this case, the endpoint). Furthermore, since it is possible to send data with different QoS using a single bulk endpoint, an application might want to prioritize the transfers by their QoS (i.e. medium latency transfers processed before high latency transfers). This kind of prioritization can be implemented/customized inside the RTOS layer (see the PHDC RTOS QoS-based scheduler page, for more information). By default, Micrium will provide an RTOS layer for both μC/OS-II and μC/OS-III. However, it is possible to create your own RTOS layer. Your layer will need to implement the functions listed in Table - OS Layer API Summary in the *Porting PHDC to an RTOS* page. For a complete API description, see the PHDC API Reference.

Function name	Operation
`USBD_PHDC_OS_Init`	Initializes all internal members / tasks.
`USBD_PHDC_OS_RdLock`	Locks read pipe.
`USBD_PHDC_OS_RdUnlock()`	Unlocks read pipe.
`USBD_PHDC_OS_WrBulkLock`	Locks write bulk pipe.
`USBD_PHDC_OS_WrBulkUnlock`	Unlocks write bulk pipe.
`USBD_PHDC_OS_WrIntrLock`	Locks write interrupt pipe.
`USBD_PHDC_OS_WrIntrUnlock()`	Unlocks write interrupt pipe.
`USBD_PHDC_OS_Reset()`	Resets OS layer members.

Table - OS Layer API Summary

Vendor Class

The Vendor class allows you to build vendor-specific devices implementing for instance a proprietary protocol. It relies on a pair of bulk endpoints to transfer data between the host and the device. Bulk transfers are typically convenient for transferring large amounts of unstructured data and provides reliable exchange of data by using an error detection and retry mechanism. Besides bulk endpoints, an optional pair of interrupt endpoints can also be used. Any operating system (OS) can work with the Vendor class provided that the OS has a driver to handle the Vendor class. Depending on the OS, the driver can be native or vendor-specific. For instance, under Microsoft Windows®, your application interacts with the WinUSB driver provided by Microsoft to communicate with the vendor device.

Vendor Class Overview

Figure - General Architecture Between Windows Host and Vendor Class in the *Vendor Class Overview* page shows the general architecture between the host and the device using the Vendor class. In this example, the host operating system is Windows.

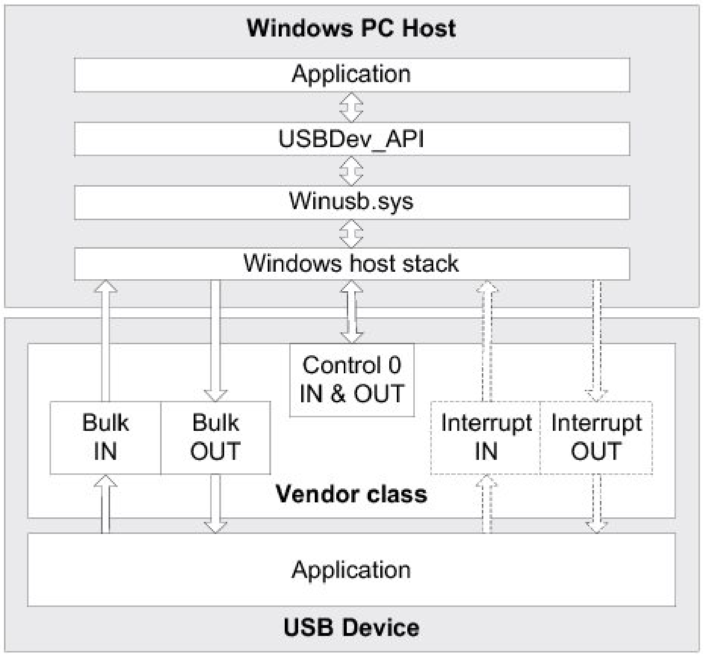


Figure - General Architecture Between Windows Host and Vendor Class

On the Windows side, the application communicates with the vendor device by interacting with the USBDev_API library. This library provided by Micrium offers an API to manage a device and its associated pipes, and to communicate with the device through control, bulk and interrupt endpoints. USBDev_API is a wrapper that allows the use of the WinUSB functions exposed by Winusb.dll.

On the device side, the Vendor class is composed of the following endpoints:

- A pair of control IN and OUT endpoints called the default endpoint.
- A pair of bulk IN and OUT endpoints.
- A pair of interrupt IN and OUT endpoints. This pair is optional.

Table - Vendor Class Endpoints Usage in the *Vendor Class Overview* page indicates the usage of the different endpoints:

Endpoint	Direction	Usage
Control IN Control OUT	Device-to-host Host-to-device	Standard requests for enumeration and vendor-specific requests.
Bulk IN Bulk OUT	Device-to-host Host-to-device	Raw data communication. Data can be structured according to a proprietary protocol.
Interrupt IN Interrupt OUT	Device-to-host Host-to-device	Raw data communication or notification. Data can be structured according to a proprietary protocol.

Table - Vendor Class Endpoints Usage

The device application can use bulk and interrupt endpoints to send or receive data to or from the host. It can only use the default endpoint to decode vendor-specific requests sent by the host. The standard requests are managed internally by the Core layer of μC/USB-Device.

Vendor Class Configuration

General Configuration

Some constants are available to customize the class. These constants are located in the USB device configuration file, `usbd_cfg.h`. Table - General Configuration Constants Summary in the *Vendor Class Configuration* page shows their description.

Constant	Description	Possible Values
`USBD_VENDOR_CFG_MAX_NBR_DEV`	Configures the maximum number of class instances. Unless you plan on having multiple configurations or interfaces using different class instances, this can be set to **1**.	From 1 to 254. Default value is **1**.
`USBD_VENDOR_CFG_MAX_NBR_CFG`	Configures the maximum number of configuration in which Vendor class is used. Keep in mind that if you use a high-speed device, two configurations will be built, one for full-speed and another for high-speed.	From 1 (low- and full-speed) or 2 (high-speed) to 254. Default value is **2**.
`USBD_VENDOR_CFG_MAX_NBR_MS_EXT_PROPERTY`	Configures the maximum number of Microsoft extended properties that can be defined per Vendor class instance. For more information on Microsoft OS descriptors and extended properties, refer to the Microsoft *Hardware Dev Center* .	From 1 to 255. Default value is **1**.

Table - General Configuration Constants Summary

Class Instance Configuration

Before starting the communication phase, your application needs to initialize and configure the class to suit its needs. Table - Vendor Class Initialization API Summary in the *Vendor Class Configuration* page summarizes the initialization functions provided by the Vendor class. For more details about the functions parameters, refer to the Vendor Class Functions reference.

Function name	Operation
`USBD_Vendor_Init()`	Initializes Vendor class internal structures and variables.
`USBD_Vendor_Add()`	Creates a new instance of Vendor class.
`USBD_Vendor_CfgAdd()`	Adds Vendor instance to the specified device configuration.
`USBD_Vendor_MS_ExtPropertyAdd()`	Adds a Microsoft extended property to the Vendor class instance. Calling this function is not mandatory. You must set `USBD_CFG_MS_DESC_EN` to `DEF_ENABLED` before using this function.

Table - Vendor Class Initialization API Summary

You need to call these functions in the order shown below to successfully initialize the Vendor class:

1. Call `USBD_Vendor_Init()`
   This is the first function you should call and you should do it only once even if you use multiple class instances. This function initializes all internal structures and variables that the class needs.

2. Call `USBD_Vendor_Add()`
   This function allocates a Vendor class instance. This function allows you to include a pair of interrupt endpoints for the considered class instance. If the interrupt endpoints are included, the polling interval can also be indicated. The polling interval will be the same for interrupt IN and OUT endpoints. Moreover, another parameter lets you specify a callback function used when receiving vendor requests. This callback allows the decoding of vendor-specific requests utilized by a proprietary protocol.

3. Call `USBD_Vendor_CfgAdd()`
   Once the Vendor class instance has been created, you must add it to a specific configuration.

4. Optional: Call `USBD_Vendor_MS_ExtPropertyAdd()`
   If you plan to use the Microsoft OS descriptors in your design, you can call this function to add Microsoft extended properties to your Vendor class instance. However, calling this function is not mandatory. You must set `USBD_CFG_MS_DESC_EN` to `DEF_ENABLED` before using this function.

Listing - Vendor Class Initialization Example in the *Vendor Class Configuration* page illustrates the use of the previous functions for initializing the Vendor class.

```
(1)
static  CPU_BOOLEAN  App_USBD_Vendor_VendorReq (      CPU_INT08U       class_nbr,
                                                const USBD_SETUP_REQ  *p_setup_req);

CPU_BOOLEAN  App_USBD_Vendor_Init (CPU_INT08U  dev_nbr,
                                   CPU_INT08U  cfg_hs,
                                   CPU_INT08U  cfg_fs)
{
    USBD_ERR    err;
    CPU_INT08U  class_nbr;


    USBD_Vendor_Init(&err);                                             (2)
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }

    class_nbr = USBD_Vendor_Add(DEF_FALSE,                              (3)
                                0u,
                                App_USBD_Vendor_VendorReq,              (1)
                               &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }

    if (cfg_hs != USBD_CFG_NBR_NONE) {
        USBD_Vendor_CfgAdd(class_nbr, dev_nbr, cfg_hs, &err);           (4)
        if (err != USBD_ERR_NONE) {
            /* $$$$ Handle the error. */
        }
    }
    if (cfg_fs != USBD_CFG_NBR_NONE) {
        USBD_Vendor_CfgAdd(class_nbr, dev_nbr, cfg_fs, &err);           (5)
        if (err != USBD_ERR_NONE) {
            /* $$$$ Handle the error. */
        }
    }

#if (USBD_CFG_MS_DESC_EN == DEF_ENABLED)
    USBD_Vendor_MS_ExtPropertyAdd(class_nbr,                            (6)
                                  USBD_MS_PROPERTY_TYPE_REG_SZ,
                                  App_USBD_Vendor_MS_PropertyNameGUID,
                                  sizeof(App_USBD_Vendor_MS_PropertyNameGUID),
                                  App_USBD_Vendor_MS_GUID,
                                  sizeof(App_USBD_Vendor_MS_GUID),
                                 &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
#endif
}
```

Listing - Vendor Class Initialization Example

(1) Provide an application callback for vendor requests decoding.

(2) Initialize Vendor internal structures, variables.

(3) Create a new Vendor class instance. In this example, `DEF_FALSE` indicates that no interrupt endpoints are used. Thus, the polling interval is set to 0. The callback `App_USBD_Vendor_VendorReq()` is passed to the function.

(4) Check if the high-speed configuration is active and proceed to add the Vendor instance previously created to this configuration.

(5) Check if the full-speed configuration is active and proceed to add the Vendor instance to this configuration.

(6) Adds a Microsoft GUID as a Microsoft extended property of the vendor class instance.

Listing - Vendor Class Initialization Example in the *Vendor Class Configuration* page also illustrates an example of multiple configurations. The functions `USBD_Vendor_Add()` and `USBD_Vendor_CfgAdd()` allow you to create multiple configurations and multiples instances architecture. Refer to the Class Instance Concept page for more details about multiple class instances.

Vendor Class Instance Communication

General

The Vendor class offers the following functions to communicate with the host. For more details about the functions parameters, refer to the Vendor Class Functions reference.

Function name	Operation
`USBD_Vendor_Rd()`	Receives data from host through bulk OUT endpoint. This function is blocking.
`USBD_Vendor_Wr()`	Sends data to host through bulk IN endpoint. This function is blocking.
`USBD_Vendor_RdAsync()`	Receives data from host through bulk OUT endpoint. This function is non-blocking.
`USBD_Vendor_WrAsync()`	Sends data to host through bulk IN endpoint. This function is non-blocking.
`USBD_Vendor_IntrRd()`	Receives data from host through interrupt OUT endpoint. This function is blocking.
`USBD_Vendor_IntrWr()`	Sends data to host through interrupt IN endpoint. This function is blocking.
`USBD_Vendor_IntrRdAsync()`	Receives data from host through interrupt OUT endpoint. This function is non-blocking.
`USBD_Vendor_IntrWrAsync()`	Sends data to host through interrupt IN endpoint. This function is non-blocking.

Table - Vendor Communication API Summary

The vendor requests are also another way to communicate with the host. When managing vendor requests sent by the host, the application can receive or send data from or to the host using the control endpoint. For that, you will need to provide an application callback passed as a parameter of `USBD_Vendor_Add` .

Synchronous Communication

Synchronous communication means that the transfer is blocking. Upon function call, the application blocks until the transfer completes with or without an error. A timeout can be specified to avoid waiting forever.

Listing - Synchronous Bulk Read and Write Example in the *Vendor Class Instance Communication* page presents a read and write example to receive data from the host using the bulk OUT endpoint and to send data to the host using the bulk IN endpoint.

```
CPU_INT08U  rx_buf[2];
CPU_INT08U  tx_buf[2];
USBD_ERR    err;


(void)USBD_Vendor_Rd(         class_nbr,                                       (1)
                     (void *)&rx_buf[0],                                       (2)
                              2u,
                              0u,                                              (3)
                             &err);
if (err != USBD_ERR_NONE) {
    /* $$$$ Handle the error. */
}

(void)USBD_Vendor_Wr(         class_nbr,                                       (1)
                     (void *)&tx_buf[0],                                       (4)
                              2u,
                              0u,                                              (3)
                              DEF_FALSE,                                       (5)
                             &err);
if (err != USBD_ERR_NONE) {
    /* $$$$ Handle the error. */
}
```

Listing - Synchronous Bulk Read and Write Example

(1) The class instance number created with `USBD_Vendor_Add()` will serve internally to the Vendor class to route the transfer to the proper bulk OUT or IN endpoint.

(2) The application must ensure that the buffer provided to the function is large enough to accommodate all the data. Otherwise, synchronization issues might happen.

(3) In order to avoid an infinite blocking situation, a timeout expressed in milliseconds can be specified. A value of '0' makes the application task wait forever.

(4) The application provides the initialized transmit buffer.

(5) If this flag is set to `DEF_TRUE` and the transfer length is multiple of the endpoint maximum packet size, the device stack will send a zero-length packet to the host to signal the end of the transfer.

The use of interrupt endpoint communication functions, `USBD_Vendor_IntrRd()` and `USBD_Vendor_IntrWr()`, is similar to bulk endpoint communication functions presented in Listing - Synchronous Bulk Read and Write Example in the *Vendor Class Instance Communication* page.

Asynchronous Communication

Asynchronous communication means that the transfer is non-blocking. Upon function call, the application passes the transfer information to the device stack and does not block. Other application processing can be done while the transfer is in progress over the USB bus. Once the transfer has completed, a callback function is called by the device stack to inform the application about the transfer completion. Listing - Asynchronous Bulk Read and Write Example in the *Vendor Class Instance Communication* page shows an example of asynchronous read and write.

```
void App_USBD_Vendor_Comm (CPU_INT08U  class_nbr)
{
    CPU_INT08U  rx_buf[2];
    CPU_INT08U  tx_buf[2];
    USBD_ERR    err;


    USBD_Vendor_RdAsync(         class_nbr,                                  (1)
                        (void *)&rx_buf[0],                                  (2)
                                 2u,
                                 App_USBD_Vendor_RxCmpl,                     (3)
                        (void *) 0u,                                         (4)
                                &err);
    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
    USBD_Vendor_WrAsync(         class_nbr,                                  (1)
                        (void *)&tx_buf[0],                                  (5)
                                 2u,
                                 App_USBD_Vendor_TxCmpl,                     (3)
                        (void *) 0u,                                         (4)
                                 DEF_FALSE,                                  (6)
                                &err);

    if (err != USBD_ERR_NONE) {
        /* $$$$ Handle the error. */
    }
}


static  void  App_USBD_Vendor_RxCmpl (CPU_INT08U   class_nbr,                (3)
                                      void        *p_buf,
                                      CPU_INT32U   buf_len,
                                      CPU_INT32U   xfer_len,
                                      void        *p_callback_arg,
                                      USBD_ERR     err)
{
    (void)class_nbr;
    (void)p_buf;
    (void)buf_len;
    (void)xfer_len;
    (void)p_callback_arg;                                           (4)

    if (err == USBD_ERR_NONE) {
        /* $$$$ Do some processing. */
    } else {
        /* $$$$ Handle the error. */
    }
}


static  void  App_USBD_Vendor_TxCmpl (CPU_INT08U   class_nbr,                (3)
                                      void        *p_buf,
                                      CPU_INT32U   buf_len,
                                      CPU_INT32U   xfer_len,
                                      void        *p_callback_arg,
                                      USBD_ERR     err)
{
    (void)class_nbr;
    (void)p_buf;
    (void)buf_len;
    (void)xfer_len;
    (void)p_callback_arg;                                                    (4)

    if (err == USBD_ERR_NONE) {
        /* $$$$ Do some processing. */
    } else {
        /* $$$$ Handle the error. */
    }
}
```

Listing - Asynchronous Bulk Read and Write Example

(1) The class instance number serves internally to the Vendor class to route the transfer to the proper bulk OUT or IN endpoint.

(2) The application must ensure that the buffer provided is large enough to accommodate all the data. Otherwise, there may be synchronization issues.

(3) The application provides a callback function pointer passed as a parameter. Upon completion of the transfer, the device stack calls this callback function so that the application can finalize the transfer by analyzing the transfer result. For instance, upon read operation completion, the application may do a certain processing with the received data. Upon write completion, the application may indicate if the write was successful and how many bytes were sent.

(4) An argument associated to the callback can be also passed. Then in the callback context, some private information can be retrieved.

(5) The application provides the initialized transmit buffer.

(6) If this flag is set to `DEF_TRUE` and the transfer length is a multiple of the endpoint maximum packet size, the device stack will send a zero-length packet to the host to signal the end of transfer.

The use of interrupt endpoint communication functions, `USBD_Vendor_IntrRdAsync()` and `USBD_Vendor_IntrWrAsync()`, is similar to bulk endpoint communication functions presented in Listing - Asynchronous Bulk Read and Write Example in the *Vendor Class Instance Communication* page.

Vendor Request

The USB 2.0 specification defines three types of requests: standard, class and vendor. All standard requests are handled directly by the core layer. Any class request will be managed by the proper associated class. The vendor request may be processed by the vendor class. You must provide an application callback as a parameter of `USBD_Vendor_Add` (as shown in Listing - Vendor Class Initialization Example in the *Vendor Class Configuration* page) to be able to process one or more vendor requests. Once a vendor request is received by the USB device, it must be decoded properly. Listing - Example of Vendor Request Decoding in the *Vendor Class Instance Communication* page shows an example of vendor request decoding. Certain request may require to receive or send from or to the host during the data stage of a control transfer. If no data stage is present, you just have to decode the Setup packet. This example shows the three types of data stage management: no data, data OUT and data IN.

```
#define  APP_VENDOR_REQ_NO_DATA                     0x01u
#define  APP_VENDOR_REQ_RECEIVE_DATA_FROM_HOST      0x02u
#define  APP_VENDOR_REQ_SEND_DATA_TO_HOST           0x03u


#define  APP_VENDOR_REQ_DATA_BUF_SIZE                 50u

static  CPU_INT08U   AppVendorReqBuf[APP_VENDOR_REQ_DATA_BUF_SIZE];


static  CPU_BOOLEAN  App_USBD_Vendor_VendorReq (       CPU_INT08U       class_nbr,
                                                       CPU_INT08U       dev_nbr,
                                                const  USBD_SETUP_REQ  *p_setup_req)    (1)
{
    CPU_BOOLEAN  valid;
    USBD_ERR     err_usb;
    CPU_INT16U   req_len;


    (void)&class_nbr;

    switch(p_setup_req->bRequest) {                                                     (2)
        case APP_VENDOR_REQ_NO_DATA:                                                    (3)
             APP_TRACE_DBG(("Vendor request [0x%X]:\r\n", p_setup_req->bRequest));
             APP_TRACE_DBG(("wIndex  = %d\r\n",           p_setup_req->wIndex));
             APP_TRACE_DBG(("wLength = %d\r\n",           p_setup_req->wLength));
             APP_TRACE_DBG(("wValue  = %d\r\n",           p_setup_req->wValue));
             valid = DEF_OK;
             break;

        case APP_VENDOR_REQ_RECEIVE_DATA_FROM_HOST:                                     (4)
             req_len = p_setup_req->wLength;
             if (req_len > APP_VENDOR_REQ_DATA_BUF_SIZE) {
                 return (DEF_FAIL);                             /* Not enough room to receive data.
*/
             }
             APP_TRACE_DBG(("Vendor request [0x%X]:\r\n", p_setup_req->bRequest));
                                                                /* Receive data via Control OUT EP.
*/
             (void)USBD_CtrlRx(         dev_nbr,
                               (void *)&AppVendorReqBuf[0u],
                                        req_len,
                                        0u,                     /* Wait transfer completion forever.
*/
                                       &err_usb);
             if (err_usb != USBD_ERR_NONE) {
                 APP_TRACE_DBG(("Error receiving data from host: %d\r\n", err_usb));
                 valid = DEF_FAIL;
             } else {
                 APP_TRACE_DBG(("wIndex  = %d\r\n", p_setup_req->wIndex));
                 APP_TRACE_DBG(("wLength = %d\r\n", p_setup_req->wLength));
                 APP_TRACE_DBG(("wValue  = %d\r\n", p_setup_req->wValue));
                 APP_TRACE_DBG(("Received %d octets from host via Control EP OUT\r\n", req_len));
                 valid = DEF_OK;
             }
             break;

        case APP_VENDOR_REQ_SEND_DATA_TO_HOST:                                      (5)
             APP_TRACE_DBG(("Vendor request [0x%X]:\r\n", p_setup_req->bRequest));
             req_len = APP_VENDOR_REQ_DATA_BUF_SIZE;
             Mem_Set((void *)&AppVendorReqBuf[0u],              /* Fill buf with a pattern.
*/
                             'A',
                             req_len);
                                                                /* Send data via Control IN EP.
*/
             (void)USBD_CtrlTx(         dev_nbr,
                                (void *)&AppVendorReqBuf[0u],
                                         req_len,
                                         0u,                    /* Wait transfer completion forever.
*/
                                         DEF_NO,
                                        &err_usb);
            if (err_usb != USBD_ERR_NONE) {
                APP_TRACE_DBG(("Error sending data to host: %d\r\n", err_usb));
                valid = DEF_FAIL;
            } else {
                APP_TRACE_DBG(("wIndex  = %d\r\n", p_setup_req->wIndex));
                APP_TRACE_DBG(("wLength = %d\r\n", p_setup_req->wLength));
                APP_TRACE_DBG(("wValue  = %d\r\n", p_setup_req->wValue));
                APP_TRACE_DBG(("Sent %d octets to host via Control EP IN\r\n", req_len));
                valid = DEF_OK;
            }
            break;

        default:                                                                  (6)
            valid = DEF_FAIL;                                 /* Request is not supported.
*/
            break;
    }
    return (valid);
}
```

Listing - Example of Vendor Request Decoding

(1) The core will pass to your application the Setup packet content. The structure `USBD_SETUP_REQ` contains the same fields as defined by the USB 2.0 specification (refer to section "9.3 USB Device Requests" of the specification for more details):

```
typedef  struct  usbd_setup_req {
    CPU_INT08U  bmRequestType;             /* Characteristics of request.
*/
    CPU_INT08U  bRequest;                  /* Specific request.
*/
    CPU_INT16U  wValue;                    /* Varies according to request.
*/
    CPU_INT16U  wIndex;                    /* Varies according to request; typically used as
index.*/
    CPU_INT16U  wLength;                   /* Transfer length if data stage present.
*/
} USBD_SETUP_REQ;
```

(2) Determine the request. You may use a `switch` statement if you are using different requests. In this example, there are three different requests corresponding to the three types of data stage: `APP_VENDOR_REQ_NO_DATA`, `APP_VENDOR_REQ_RECEIVE_DATA_FROM_HOST`, `APP_VENDOR_REQ_SEND_DATA_TO_HOST.`

(3) If no data stage is present, you just need to decode the other fields. The presence of a data stage or not is indicated by the field `wLength` being non-null or null.

(4) If the host sends data to the device, you must call the function `USBD_CtrlRx()` . The buffer provided should be able to hold up to `wLength` bytes. If any error occurs, return `DEF_FAIL` to the core that will stall the status stage of the control transfer indicating to the host that the request cannot be processed. `DEF_OK` is returned in case of success.

(5) If the host receives data from the device, you must call the function `USBD_CtrlTx` . If any error occurs, return `DEF_FAIL` to the core that will stall the status stage of the control transfer indicating to the host that the request cannot be processed. `DEF_OK` is returned in case of success.

(6) In this example, all requests not recognized are marked by returning `DEF_FAIL` to the core. This one will stall the data or status stage of the control transfer indicating to the host that the request is not supported.

The host sends vendor requests using the function `USBDev_CtrlReq()`. Refer to the page USBDev_API for more details about how to send vendor requests on the host side.

USBDev_API

The Windows host application communicates with a vendor device through *USBDev_API*. The latter is a wrapper developed by Micrium allowing the application to access the WinUSB functionalities to manage a USB device. Windows USB (WinUSB) is a generic driver for USB devices. The WinUSB architecture consists of a kernel-mode driver (`winusb.sys`) and a user-mode dynamic link library (`winusb.dll`) that exposes WinUSB functions. USBDev_API eases the use of WinUSB by providing a comprehensive API (refer to the USBDev_API Functions Reference for the complete list). Figure - USBDev_API and WinUSB in the *USBDev_API* page shows the USBDev_API library and WinUSB.

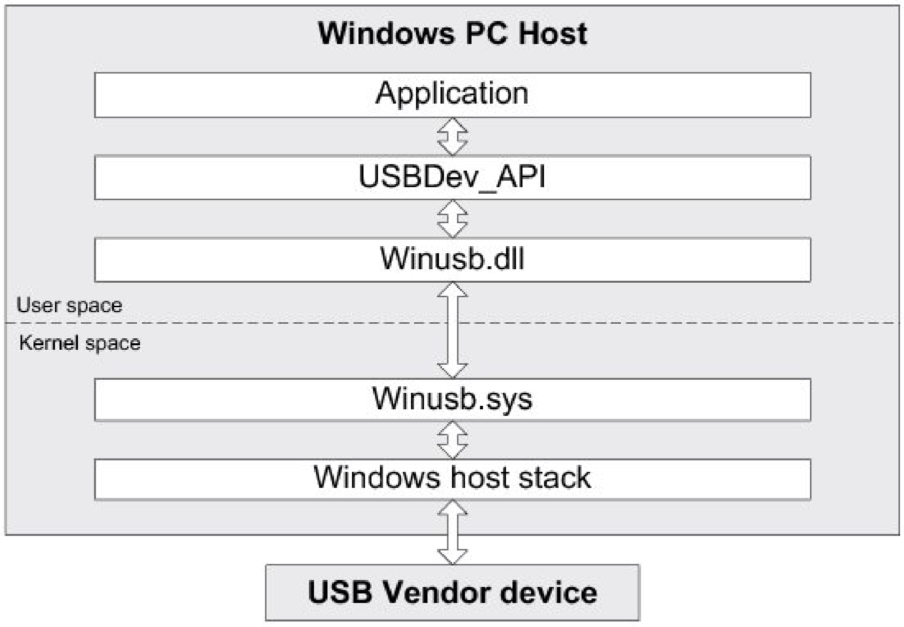


Figure - USBDev_API and WinUSB

For more about WinUSB architecture, refer to Microsoft's MSDN online documentation at: `http://msdn.microsoft.com/en-us/library/ff540207(v=VS.85).aspx`

Management

`USBDev_API` offers the following functions to manage a device and its function's pipes.

Function name	Operation
`USBDev_DevQtyGet`	Gets number of devices belonging to a specified Globally Unique IDentifier (GUID) and connected to the host. Refer to the GUID section for more details about the GUID.
`USBDev_Open()`	Opens a device.
`USBDev_Close`	Closes a device.
`USBDev_BulkIn_Open`	Opens a bulk IN pipe.
`USBDev_BulkOut_Open`	Opens a bulk OUT pipe.
`USBDev_IntrIn_Open`	Opens an interrupt IN pipe.
`USBDev_IntrOut_Open`	Opens an interrupt OUT pipe.
`USBDev_PipeClose`	Closes a pipe.

Table - USBDev_API Device and Pipe Management API

Listing - USBDev_API Device and Pipe Management Example in the *USBDev_API* page shows an example of device and pipe management. The steps to manage a device typically consist in:

- Opening the vendor device connected to the host.
- Opening required pipes for this device.
- Communicating with the device via the open pipes.
- Closing pipes.
- Closing the device.

```
HANDLE  dev_handle;
HANDLE  bulk_in_handle;
HANDLE  bulk_out_handle;
DWORD   err;
DWORD   nbr_dev;


nbr_dev = USBDev_DevQtyGet(USBDev_GUID, &err);                              (1)
if (err != ERROR_SUCCESS) {
    /* $$$$ Handle the error. */
}

dev_handle = USBDev_Open(USBDev_GUID, 1, &err);                             (2)
if (dev_handle == INVALID_HANDLE_VALUE) {
    /* $$$$ Handle the error. */
}

bulk_in_handle = USBDev_BulkIn_Open(dev_handle, 0, 0, &err);                (3)
if (bulk_in_handle == INVALID_HANDLE_VALUE) {
    /* $$$$ Handle the error. */
}

bulk_out_handle = USBDev_BulkOut_Open(dev_handle, 0, 0, &err);              (3)
if (bulk_out_handle == INVALID_HANDLE_VALUE) {
    /* $$$$ Handle the error. */
}

/* Communicate with the device. */                                          (4)

USBDev_PipeClose(bulk_in_handle, &err);                                     (5)
if (err != ERROR_SUCCESS) {
    /* $$$$ Handle the error. */
}

USBDev_PipeClose(bulk_out_handle, &err);
if (err != ERROR_SUCCESS) {
    /* $$$$ Handle the error. */
}

USBDev_Close(dev_handle, &err);                                             (6)
if (err != ERROR_SUCCESS) {
    /* $$$$ Handle the error. */
}
```

Listing - USBDev_API Device and Pipe Management Example

(1) Get the number of devices connected to the host under the specified GUID. A GUID provides a mechanism for applications to communicate with a driver assigned to devices in a class. The number of devices could be used in a loop to open at once all the devices. In this example, one device is assumed.

(2) Open the device by retrieving a general device handle. This handle will be used for pipe management and communication.

(3) Open a bulk pipe by retrieving a pipe handle. In the example, a bulk IN and a bulk OUT

pipes are open. If the pipe does not exist for this device, an error is returned. When opening a pipe, the interface number and alternate setting number are specified. In the example, bulk IN and OUT pipes are part of the default interface. Opening an interrupt IN and OUT pipes with `USBDev_IntIn_Open()` or `USBDev_IntOut_Open()` is similar to bulk IN and OUT pipes.

(4) Transferring data on the open pipes can take place now. The pipe communication is described in the Communication section.

(5) Close a pipe by passing the associated handle. The closing operation aborts any transfer in progress for the pipe and frees any allocated resources.

(6) Close the device by passing the associated handle. The operation frees any allocated resources for this device. If a pipe has not been closed by the application, this function will close any forgotten open pipes.

Communication

Synchronous

Synchronous communication means that the transfer is blocking. Upon function call, the application blocks until the end of transfer is completed with or without an error. A timeout can be specified to avoid waiting forever. Listing - USBDev_API Synchronous Read and Write Example in the *USBDev_API* page presents a read and write example using a bulk IN pipe and a bulk OUT pipe.

```
UCHAR  rx_buf[2];
UCHAR  tx_buf[2];
DWORD  err;


(void)USBDev_PipeRd(bulk_in_handle,                                          (1)
                   &rx_buf[0],                                               (2)
                    2u,
                    5000u,                                                   (3)
                   &err);
if (err != ERROR_SUCCESS) {
    /* $$$$ Handle the error. */
}

(void)USBDev_PipeWr(bulk_out_handle,                                         (1)
                   &tx_buf[0],                                               (4)
                    2u,
                    5000u,                                                   (3)
                   &err);
if (err != ERROR_SUCCESS) {
    /* $$$$ Handle the error. */
}
```

Listing - USBDev_API Synchronous Read and Write Example

(1) The pipe handle gotten with `USBDev_BulkIn_Open()` or `USBDev_BulkOut_Open()` is passed to the function to schedule the transfer for the desired pipe.

(2) The application provides a receive buffer to store the data sent by the device.

(3) In order to avoid an infinite blocking situation, a timeout expressed in milliseconds can be specified. A value of ‘0’ makes the application thread wait forever. In the example, a timeout of 5 seconds is set.

(4) The application provides the transmit buffer that contains the data for the device.

Asynchronous

Asynchronous communication means that the transfer is non-blocking. Upon function call, the application passes the transfer information to the device stack and does not block. Other application processing can be done while the transfer is in progress over the USB bus. Once the transfer has completed, a callback is called by USBDev_API to inform the application about the transfer completion.

Listing - USBDev_API Asynchronous Read Example in the *USBDev_API* page presents a read example. The asynchronous write is not offered by USBDev_API.

```
UCHAR  rx_buf[2];
DWORD  err;


USBDev_PipeRdAsync(        bulk_in_handle,                                    (1)
                          &rx_buf[0],                                         (2)
                           2u,
                           App_PipeRdAsyncComplete,                           (3)
                   (void *)0u,                                                (4)
                          &err);
if (err != ERROR_SUCCESS) {
    /* $$$$ Handle the error. */
}

static  void  App_PipeRdAsyncComplete(void   *p_buf,                          (3)
                                      DWORD   buf_len,
                                      DWORD   xfer_len,
                                      void   *p_callback_arg,
                                      DWORD   err)
{
    (void)p_buf;
    (void)buf_len;
    (void)xfer_len;
    (void)p_callback_arg;                                                     (4)

    if (err == ERROR_SUCCESS) {
        /* $$$$ Process the received data. */
    } else {
        /* $$$$ Handle the error. */
    }
}
```

Listing - USBDev_API Asynchronous Read Example

(1) The pipe handle gotten with `USBDev_BulkIn_Open()` is passed to the function to schedule the transfer for the desired pipe.

(2) The application provides a receive buffer to store the data sent by the device.

(3) The application provides a callback passed as a parameter. Upon completion of the transfer, USBDev_API calls this callback so that the application can finalize the transfer by analyzing the transfer result. For instance, upon read operation completion, the application may do a certain processing with the received data.

(4) An argument associated to the callback can also be passed. Then, in the callback context, some private information can be retrieved.

Control Transfer

You can communicate with the device through the default control endpoint by using the function `USBDev_CtrlReq()` . You will be able to define the three types of requests (standard, class or vendor) and to use the data stage or not of a control transfer to move data. More details about control transfers can be found in “Universal Serial Bus Specification, Revision 2.0, April 27, 2000”, section 5.5 and 9.3.

Using the Vendor Class Demo Application

Micrium provides a demo application that lets you test and evaluate the class implementation. Source template files are provided for the device. Executable and source files are provided for Windows host PC.

Note that the demo application provided by Micriµm is only an example and is intended to be used as a starting point to develop your own application.

Configuring PC and Device Applications for Vendor Class

The demo used between the host and the device is the *Echo* demo. This demo implements a simple protocol allowing the device to echo the data sent by the host.

On the device side, the demo application file, `app_usbd_vendor.c`, provided for µC/OS-II and µC/OS-III is located in this folder:

- `\Micrium\Software\uC-USB-Device-V4\App\Device\`

`app_usbd_vendor.c` contains the Echo demo available in two versions:

- The *Echo Sync* demo exercises the synchronous communication API described in the Synchronous Communication section.
- The *Echo Async* demo exercises the asynchronous communication API described in the Asynchronous Communication section.

The use of these constants defined usually in `app_cfg.h` or `app_usbd_cfg.h` allows you to use the vendor demo application.

Constant	Description	File
`APP_CFG_USBD_VENDOR_EN`	General constant to enable the Vendor class demo application. Must be set to `DEF_ENABLED`.	`app_usbd_cfg.h`
`APP_CFG_USBD_VENDOR_ECHO_SYNC_EN`	Enables or disables the Echo Sync demo. The possible values are `DEF_ENABLED` or `DEF_DISABLED`.	`app_usbd_cfg.h`
`APP_CFG_USBD_VENDOR_ECHO_ASYNC_EN`	Enables or disables the Echo Async demo. The possible values are `DEF_ENABLED` or `DEF_DISABLED`.	`app_usbd_cfg.h`
`APP_CFG_USBD_VENDOR_ECHO_SYNC_TASK_PRIO`	Priority of the task used by the Echo Sync demo.	`app_cfg.h`
`APP_CFG_USBD_VENDOR_ECHO_ASYNC_TASK_PRIO`	Priority of the task used by the Echo Async demo.	`app_cfg.h`
`APP_CFG_USBD_VENDOR_TASK_STK_SIZE`	Stack size of the tasks used by Echo Sync and Async demos. A default value can be 256.	`app_cfg.h`

Table - Device Application Constants Configuration

`APP_CFG_USBD_VENDOR_ECHO_SYNC_EN` and `APP_CFG_USBD_VENDOR_ECHO_ASYNC_EN` can be set to `DEF_ENABLED` at the same time. The vendor device created will be a composite device formed with two vendor interfaces. One will represent the Echo Sync demo and the other the Echo Async demo.

On the Windows side, the demo application file, `app_vendor_echo.c`, is part of a Visual Studio solution located in this folder:

```
\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\Vendor\Visual Studio 2010
```

`app_vendor_echo.c` allows you to test:

- One single device. That is Echo Sync or Async demo is enabled on the device side.
- One composite device. That is Echo Sync and Async demos are both enabled on the device side.
- Multiple devices (single or composite devices).

`app_vendor_echo.c` contains some constants to customize the demo.

Constant	Description
`APP_CFG_RX_ASYNC_EN`	Enables or disables the use of the asynchronous API for IN pipe. The possible values are `TRUE` or `FALSE`.
`APP_MAX_NBR_VENDOR_DEV`	Defines the maximum number of connected vendor devices supported by the demo.

Table - Windows Application Constants Configuration

The constants configuration for the Windows application are independent from the device application constants configuration presented in Table - Windows Application Constants Configuration in the *Using the Vendor Class Demo Application* page.

Editing an INF File

An INF file contains directives telling to Windows how to install one or several drivers for one or more devices. Refer to the About INF Files section for more details about INF file use and format. The Vendor class includes two INF files located in `\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\Vendor\INF`:

- `WinUSB_single.inf`, used if the device presents only one Vendor class interface.
- `WinUSB_composite.inf`, used if the device presents at least one Vendor class interface along with another interface.

The two INF files allows you to load the `WinUSB.sys` driver provided by Windows. `WinUSB_single.inf` defines this default hardware ID string:

```
USB\VID_FFFE&PID_1003
```

While `WinUSB_composite.inf` defines this one:

```
USB\VID_FFFE&PID_1001&MI_00
```

The hardware ID string contains the Vendor ID (VID) and Product ID (PID). In the default strings, the VID is FFFE and the PID is either 1003 or 1001. The VID/PID values should match the ones from the USB device configuration structure defined in `usb_dev_cfg.c`. Refer to the Modify Device Configuration section for more details about the USB device configuration structure.

If you want to define your own VID/PID, you must modify the previous default hardware ID strings with your VID/PID.

In the case of a composite device formed of several vendor interfaces, in order to load WinUSB.sys for each vendor interface, the manufacturer section in `WinUSB_composite.inf` can be modified as shown in Listing - INF File Example for Composite Device Formed of Several Vendor Interfaces in the *Using the Vendor Class Demo Application* page. Let's assume a device with two vendor interfaces.

```
[MyDevice_WinUSB.NTx86]
%USB\MyDevice.DeviceDesc% =USB_Install, USB\VID_FFFE&PID_1001&MI_00
%USB\MyDevice.DeviceDesc% =USB_Install, USB\VID_FFFE&PID_1001&MI_01

[MyDevice_WinUSB.NTamd64]
%USB\MyDevice.DeviceDesc% =USB_Install, USB\VID_FFFE&PID_1001&MI_00
%USB\MyDevice.DeviceDesc% =USB_Install, USB\VID_FFFE&PID_1001&MI_01

[MyDevice_WinUSB.NTia64]
%USB\MyDevice.DeviceDesc% =USB_Install, USB\VID_FFFE&PID_1001&MI_00
%USB\MyDevice.DeviceDesc% =USB_Install, USB\VID_FFFE&PID_1001&MI_01
```

Listing - INF File Example for Composite Device Formed of Several Vendor Interfaces

You can also modify the [Strings] section of the INF file in order to add the strings that best describe your device. Listing - Editable Strings in the INF File to Describe the Vendor Device in the *Using the Vendor Class Demo Application* page shows the editable `[Strings]` section common to `WinUSB_single.inf` and `WinUSB_composite.inf`.

```
[Strings]
ProviderName            ="Micrium"                                          (1)
USB\MyDevice.DeviceDesc ="Micrium Vendor Specific Device"                   (2)
ClassName               ="USB Sample Class"                                 (3)
```

Listing - Editable Strings in the INF File to Describe the Vendor Device

(1) Specify the name of your company as the driver provider.

(2) Write the name of your device.

(3) You can modify this string to give a new name to the device group in which your device will appear under Device Manager. In this example, "Micrium Vendor Specific Device" will appear under the "USB Sample Class" group. Refer to Figure - Windows Device

Manager Example for a CDC Device in the *Microsoft Windows* page for an illustration of the strings used by Windows.

Running the Vendor Class Demo Application

Figure - Echo Demo in the *Using the Vendor Class Demo Application* page illustrates the Echo demo with host and device interactions:

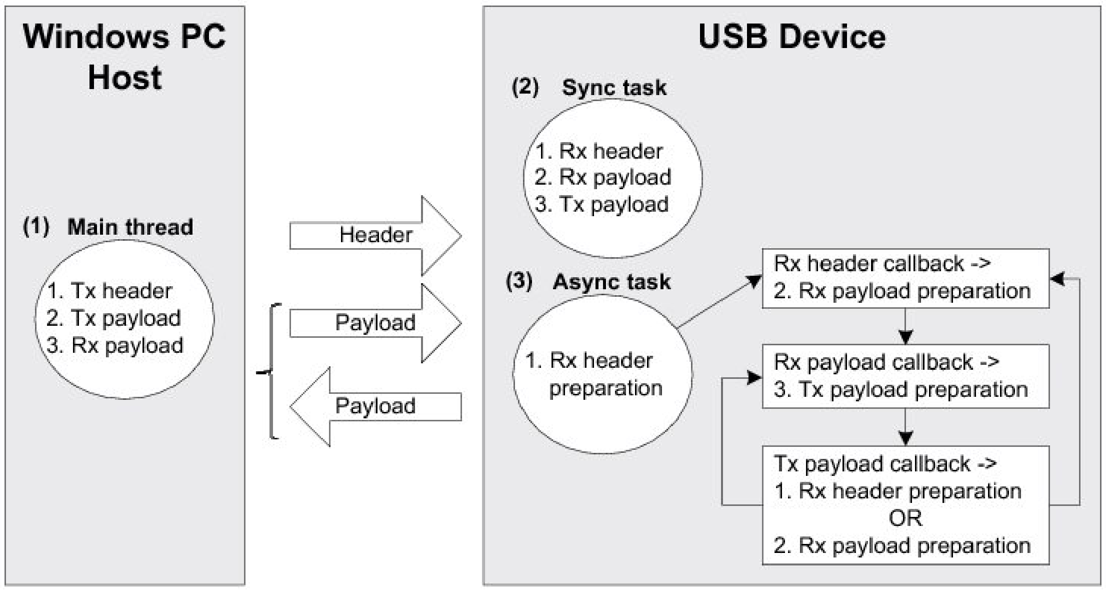


Figure - Echo Demo

(1) The Windows application executes a simple protocol consisting of sending a header indicating the total payload size, sending the data payload to the device and receiving the same data payload from the device. The entire transfer for data payload is split into small chunks of write and read operations of 512 bytes. The write operation is done using a bulk OUT endpoint and the read uses a bulk IN endpoint.

(2) On the device side, the Echo Sync uses a task that complements the Windows application execution. Each step is done synchronously. The read and write operation is the opposite of the host side in terms of USB transfer direction. Read operation implies a bulk OUT endpoint while a write implies a bulk IN endpoint.

(3) If the Echo Async is enabled, the same steps done by the Sync task are replicated but using the asynchronous API. A task is responsible to start the first asynchronous OUT transfer to receive the header. The task is also used in case of error during the protocol communication. The callback associated to the header reception is called by the device stack. It prepares the next asynchronous OUT transfer to receive the payload. The read payload callback sends back the payload to the host via an asynchronous IN transfer. The write payload callback is called and either prepares the next header reception if the entire payload has been sent to the host, or prepares a next OUT transfer to receive a new chunk of data payload.

Upon the first connection of the vendor device, Windows enumerates the device by retrieving the standard descriptors. Since Microsoft does not provide any specific driver for the Vendor class, you have to indicate to Windows which driver to load using an INF file (refer to the About INF Files section for more details about INF). The INF file tells Windows to load the WinUSB generic driver (provided by Microsoft). Indicating the INF file to Windows has to be done only once. Windows will then automatically recognize the vendor device and load the proper driver for any new connection. The process of indicating the INF file may vary according to the Windows operating system version:

- Windows XP directly opens the “Found New Hardware Wizard”. Follow the different steps of the wizard until the page where you can indicate the path of the INF file.

- Windows Vista and later won’t open a “Found New Hardware Wizard”. It will just indicate that no driver was found for the vendor device. You have to manually open the wizard. Open the Device Manager, the vendor device connected appears under the category ‘Other Devices’ with a yellow icon. Right-click on your device and choose ‘Update Driver Software...’ to open the wizard. Follow the different steps of the wizard until the page where you can indicate the path of the INF file.

The INF file is located in:

```
\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\Vendor\INF
```

Refer to the About INF Files section for more details about how to edit the INF file to match your Vendor and Product IDs.

Once the driver is successfully loaded, the Windows host application is ready to be launched. The executable is located in the following folder:

```
\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\Vendor\Visual Studio 
2010\exe\
```

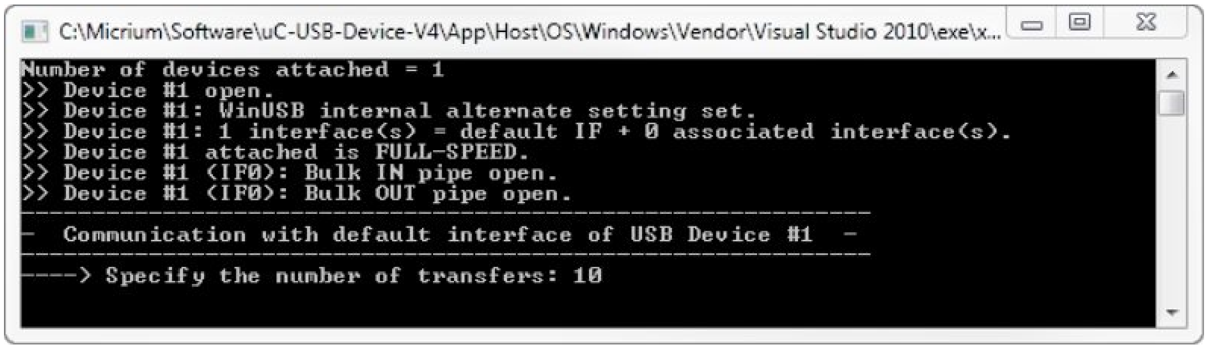
There are two executables:

- *EchoSync.exe* for the Windows application with the synchronous communication API of USBDev_API.

- *EchoAsync.exe* for the Windows application with the asynchronous IN API of USBDev_API.

The Windows application interacts with WinUSB driver via USBDev_API which is a wrapper of WinUSB driver. USBDev_API is provided by Micrium. Refer to the USBDev_API page for more details about USBDev_API and WinUSB driver.

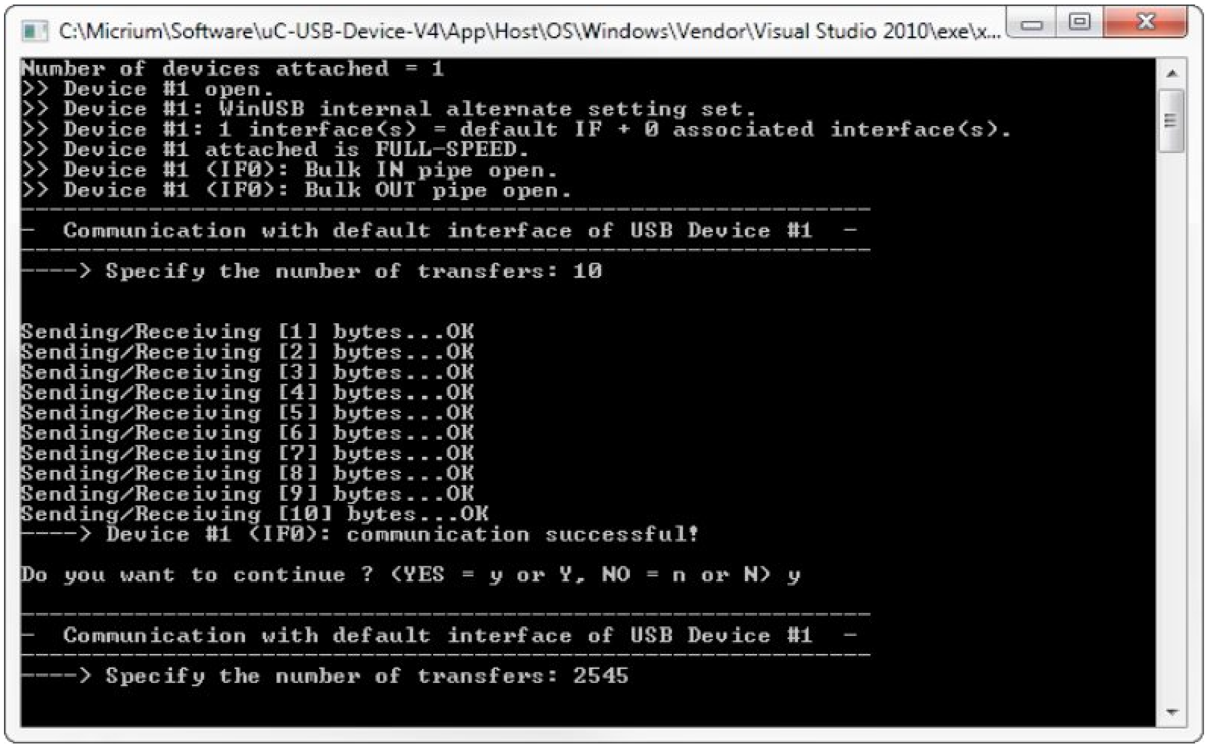
The Echo Sync or Async demo will first determine the number of vendor devices connected to the PC. For each detected device, the demo will open a bulk IN and a bulk OUT pipe. Then the demo is ready to send/receive data to/from the device. You will have to enter the maximum number of transfers you want as shown by Figure - Demo Application at Startup in the *Using the Vendor Class Demo Application* page.


C:\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\Vendor\Visual Studio 2010\exe\x...

```
Number of devices attached = 1
>> Device #1 open.
>> Device #1: WinUSB internal alternate setting set.
>> Device #1: 1 interface(s) = default IF + 0 associated interface(s).
>> Device #1 attached is FULL-SPEED.
>> Device #1 (IF0): Bulk IN pipe open.
>> Device #1 (IF0): Bulk OUT pipe open.
------------------------------------------------------------
-  Communication with default interface of USB Device #1   -
------------------------------------------------------------
----> Specify the number of transfers: 10
```

Figure - Demo Application at Startup

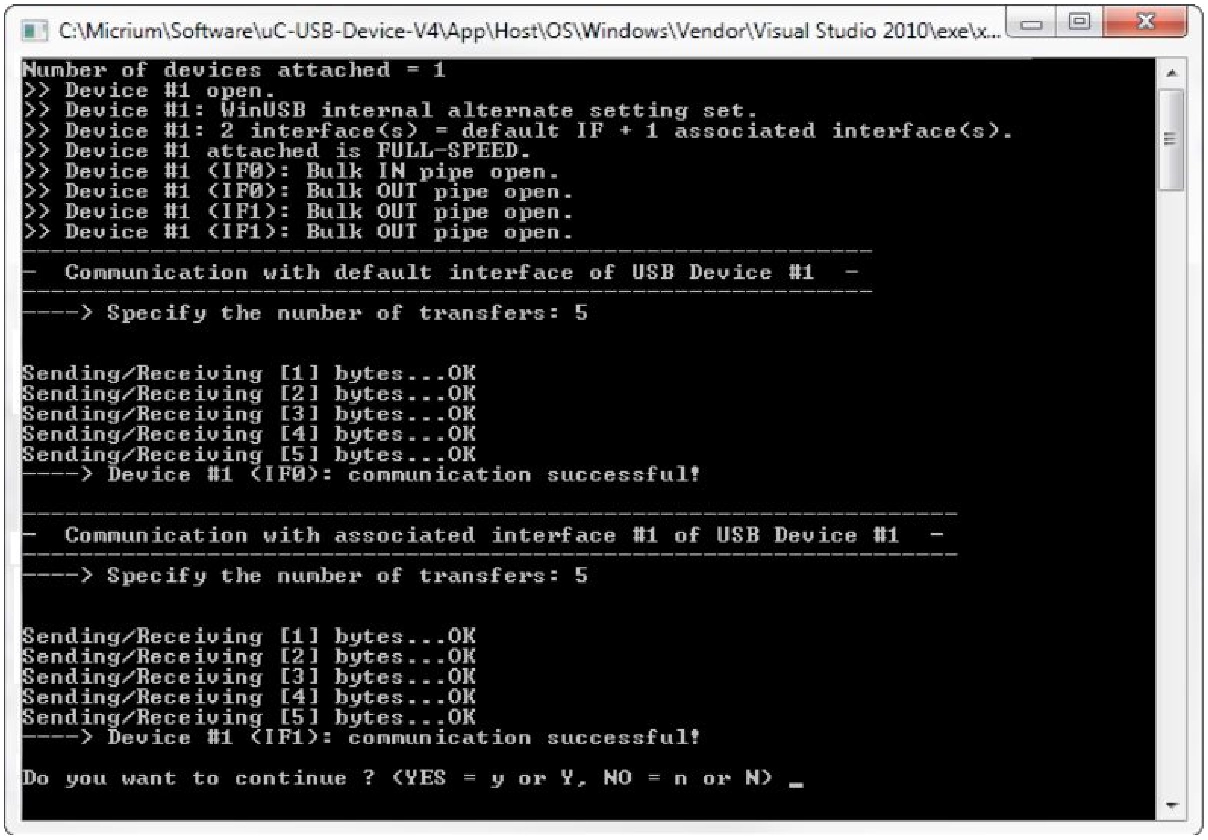
In the example of Figure - Demo Application at Startup in the *Using the Vendor Class Demo Application* page, the demo will handle 10 transfers. Each transfer is sent after the header following the simple protocol described in Figure - Echo Demo in the *Using the Vendor Class Demo Application* page. The first transfer will have a data payload of 1 byte. Then, subsequent transfers will have their size incremented by 1 byte until the last transfer. In our example, the last transfer will have 10 bytes. Figure - Demo Application Execution (Single Device) in the *Using the Vendor Class Demo Application* page presents the execution.



```
C:\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\Vendor\Visual Studio 2010\exe\x...
Number of devices attached = 1
>> Device #1 open.
>> Device #1: WinUSB internal alternate setting set.
>> Device #1: 1 interface(s) = default IF + 0 associated interface(s).
>> Device #1 attached is FULL-SPEED.
>> Device #1 (IF0): Bulk IN pipe open.
>> Device #1 (IF0): Bulk OUT pipe open.
------------------------------------------------------------
-  Communication with default interface of USB Device #1  -
------------------------------------------------------------
----> Specify the number of transfers: 10


Sending/Receiving [1] bytes...OK
Sending/Receiving [2] bytes...OK
Sending/Receiving [3] bytes...OK
Sending/Receiving [4] bytes...OK
Sending/Receiving [5] bytes...OK
Sending/Receiving [6] bytes...OK
Sending/Receiving [7] bytes...OK
Sending/Receiving [8] bytes...OK
Sending/Receiving [9] bytes...OK
Sending/Receiving [10] bytes...OK
----> Device #1 (IF0): communication successful!

Do you want to continue ? (YES = y or Y, NO = n or N) y

------------------------------------------------------------
-  Communication with default interface of USB Device #1  -
------------------------------------------------------------
----> Specify the number of transfers: 2545
```

Figure - Demo Application Execution (Single Device)

The demo will propose to do a new execution. Figure - Demo Application Execution (Single Device) in the *Using the Vendor Class Demo Application* page shows the example of a single device with 1 vendor interface. The demo is able to communicate with each vendor interface in the case of a composite device. In that case, the demo will open bulk IN and OUT pipes for each interface. You will be asked the maximum number of transfers for each interface composing the device. Figure - Demo Application Execution (Composite Device) in the *Using the Vendor Class Demo Application* page shows an example of a composite device.



C:\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\Vendor\Visual Studio 2010\exe\x...

```
Number of devices attached = 1
>> Device #1 open.
>> Device #1: WinUSB internal alternate setting set.
>> Device #1: 2 interface(s) = default IF + 1 associated interface(s).
>> Device #1 attached is FULL-SPEED.
>> Device #1 (IF0): Bulk IN pipe open.
>> Device #1 (IF0): Bulk OUT pipe open.
>> Device #1 (IF1): Bulk OUT pipe open.
>> Device #1 (IF1): Bulk OUT pipe open.
------------------------------------------------------------
-  Communication with default interface of USB Device #1  -
------------------------------------------------------------
----> Specify the number of transfers: 5


Sending/Receiving [1] bytes...OK
Sending/Receiving [2] bytes...OK
Sending/Receiving [3] bytes...OK
Sending/Receiving [4] bytes...OK
Sending/Receiving [5] bytes...OK
----> Device #1 (IF0): communication successful!

------------------------------------------------------------------
-  Communication with associated interface #1 of USB Device #1  -
------------------------------------------------------------------
----> Specify the number of transfers: 5


Sending/Receiving [1] bytes...OK
Sending/Receiving [2] bytes...OK
Sending/Receiving [3] bytes...OK
Sending/Receiving [4] bytes...OK
Sending/Receiving [5] bytes...OK
----> Device #1 (IF1): communication successful!

Do you want to continue ? (YES = y or Y, NO = n or N) _
```

Figure - Demo Application Execution (Composite Device)

GUID

A Globally Unique IDentifier (GUID) is a 128-bit value that uniquely identifies a class or other entity. Windows uses GUIDs for identifying two types of devices classes:

- Device setup class
- Device interface class

A device setup GUID encompasses devices that Windows installs in the same way and using the same class installer and co-installers. Class installers and co-installers are DLLs that provide functions related to the device installation. A device interface class GUID provides a mechanism for applications to communicate with a driver assigned to devices in a class. Refer to the Using GUIDs section for more details about the GUID.

Device setup class GUID is used in `WinUSB_single.inf` and `WinUSB_composite.inf` located in `\Micrium\Software\uC-USB-Device-V4\App\Host\OS\Windows\Vendor\INF`. These INF files define a new device setup class that will be added in the Windows registry under `HKEY_LOCAL_MACHINE\System\CurrentControlSet\Control\Class` upon first connection of a vendor device. The following entries in the INF file define the new device setup class.

```
Class     = MyDeviceClass                          ; Name of the device setup class.
ClassGuid = {11111111-2222-3333-4444-555555555555} ; Device setup class GUID
```

The INF file allows Windows to register in the registry base all the information necessary to associate the driver Winusb.sys with the connected vendor device.

The Windows Echo application is able to retrieve the attached vendor device thanks to the device interface class GUID. `WinUSB_single.inf` and `WinUSB_composite.inf` define the following device interface class GUID: `{143f20bd-7bd2-4ca6-9465-8882f2156bd6}`. The Echo application includes a header file called `usbdev_guid.h`. This header file defines the following variable:

```
GUID USBDev_GUID = {0x143f20bd,0x7bd2,0x4ca6,
{0x94,0x65,0x88,0x82,0xf2,0x15,0x6b,0xd6}};
```

`USBDev_GUID` is a structure whose fields represent the device interface class GUID defined in `WinUSB_single.inf` and `WinUSB_composite.inf`. The `USBDev_GUID` variable will be passed as a parameter to the function `USBDev_Open()`. A handle will be returned by `USBDev_Open()`. And the application uses this handle to access the device.

Debug and Trace

µC/USB-Device provides an option to enable debug traces to output transactional activity via an output port of your choice such as the console or serial port. Debugging traces allows you to see how the USB device stack behaves and is a useful troubleshooting tool when trying to debug a problem. This chapter will show you the debug and trace tools available in the USB device core as well as how to go about using them.

Using Debug Traces

Debug Trace Output

Core level debug traces are outputted from the debug task handler via an application defined trace function `USBD_Trace()`. This function is located in `app_usbd.c` and it is up to you to define how messages are outputted whether through console terminal `printf()` statements or serial `printf()` statements for example. Listing - USBD_Trace Example in the *Using Debug Traces* page shows an example of an implementation for `USBD_Trace()` with a serial `printf()` function.

```
void USBD_Trace (const CPU_CHAR *p_str)
{
    App_SerPrintf("%s", (CPU_CHAR *)p_str);
}
```

Listing - USBD_Trace Example

Debug Trace Configuration

There are several configuration constants necessary to customize the core level debugging traces. These constants are found in `usbd_cfg.h` and are summarized in Table - General Configuration Constants in the *Using Debug Traces* page.

Constant	Description
`USBD_CFG_DBG_TRACE_EN`	This constant enables core level debugging traces in the program so that transactional activity can be outputted.
`USBD_CFG_DBG_TRACE_NBR_EVENTS`	This constant configures the size of the debug event pool to store debug events.

Table - General Configuration Constants

Debug Trace Format

The debug task handler follows a simple format when outputting debug events. The format is as follows:

```
USB <timestamp> <interface number> <endpoint address> <error/info message>
```

In the event that timestamp, endpoint address, interface number or error messages are not provided, they are left void in the output. An example output is shown in Listing - Sample Debug Output in the *Using Debug Traces* page. This example corresponds to traces placed in the USB device core and device driver functions. This trace shows the enumeration process where bus events are received and related endpoints are opened in the device driver. Next, a setup event is sent to the core task followed by receiving the first Get Device Descriptor standard request.

```
USB           0           Bus Reset
USB           0  80         Drv EP DMA Open
USB           0   0         Drv EP DMA Open
USB           0           Bus Suspend
USB           0           Bus Reset
USB           0  80         Drv EP DMA Close
USB           0   0         Drv EP DMA Close
USB           0  80         Drv EP DMA Open
USB           0   0         Drv EP DMA Open
USB           0             Drv ISR Rx (Fast)
USB           0   0       Setup pkt
USB           0   0         Drv ISR Rx Cmpl (Fast)
USB           0             Drv ISR Rx (Fast)
USB           0   0         Get descriptor(Device)
USB           0  80         Drv EP FIFO Tx Len: 18
USB           0  80         Drv EP FIFO Tx Start Len: 18
USB           0             Drv ISR Rx (Fast)
USB           0  80         Drv ISR Tx Cmpl (Fast)
USB           0   0         Drv ISR Rx Cmpl (Fast)
USB           0             Drv ISR Rx (Fast)
USB           0   0         Drv EP FIFO RxZLP
USB           0             Drv ISR Rx (Fast)
...
```

Listing - Sample Debug Output

Handling Debug Events

Debug Event Pool

A pool is used to keep track of debugging events. This pool is made up of debug event structures where the size of the pool is specified by `USBD_CFG_DBG_TRACE_NBR_EVENTS` in the application configuration. Within the core, each time a new debug standard request is received, the message's details will be set into a debug event structure and queued into the pool. Once the debug event is properly queued, a ready signal is invoked to notify the debug task handler that an event is ready to be processed.

Debug Task

An OS-dependent task is used to process debug events. The debug task handler simply pends until an event ready signal is received and obtains a pointer to the first debug event structure from the pool. The details of the debug event structure is then formatted and outputted via the application trace function. At the end of the output, the debug event structure is then subsequently freed and the debug task will pend and process the next debug event structure ready. Refer to the Processing Debug Events section for details on processing debug events.

Debug Macros

Within the core, several macros are created to set debug messages. These macros are defined in `usbd_core.h` and make use of the core functions `USBD_Dbg()` and `USBD_DbgArg()` that will set up a debug event structure and put the event into the debug event pool. These macros are defined in Listing - Core Level Debug Macros in the *Handling Debug Events* page.

```
#define USBD_DBG_GENERIC(msg, ep_addr, if_nbr)                    USBD_Dbg((msg),              \
                                                                           (ep_addr),          \
                                                                           (if_nbr),           \
                                                                            USBD_ERR_NONE)

#define USBD_DBG_GENERIC_ERR(msg, ep_addr, if_nbr, err)          USBD_Dbg((msg),              \
                                                                           (ep_addr),          \
                                                                           (if_nbr),           \
                                                                           (err))

#define USBD_DBG_GENERIC_ARG(msg, ep_addr, if_nbr, arg)          USBD_DbgArg((msg),           \
                                                                              (ep_addr),       \
                                                                              (if_nbr),        \
                                                                              (CPU_INT32U)(arg),\
                                                                              (USBD_ERR_NONE))

#define USBD_DBG_GENERIC_ARG_ERR(msg, ep_addr, if_nbr, arg, err) USBD_DbgArg((msg),           \
                                                                              (ep_addr),       \
                                                                              (if_nbr),        \
                                                                              (CPU_INT32U)(arg),\
                                                                              (err))
```

Listing - Core Level Debug Macros

There are subtle yet important differences between each debug macro. The first debug macro is the most simple, specifying just the debug message, endpoint address and interface number as parameters. The second and third macros differ in the last parameter where one specifies the error and the other specifies an argument of choice. The last macro lets the caller specify all details including both error and argument.

Furthermore, core level debug macros can be further mapped to other macros to simplify the repetition of endpoint address and interface number parameters. Listing - Mapped Core Tracing Macros in the *Handling Debug Events* page shows an example of a bus specific debug macro and a standard debug macro found in `usbd_core.c`.

```
#define  USBD_DBG_CORE_BUS(msg)             USBD_DBG_GENERIC((msg),                \
                                                              USBD_EP_ADDR_NONE,   \
                                                              USBD_IF_NBR_NONE)

#define  USBD_DBG_CORE_STD(msg)             USBD_DBG_GENERIC((msg),                \
                                                              0u,
                                                              USBD_IF_NBR_NONE)
```

Listing - Mapped Core Tracing Macros

Porting uC-USB-Device to your RTOS

C/USB-Device requires a Real-Time Operating System (RTOS). In order to make it usable with nearly any RTOS available on the market, it has been designed to be easily portable. Micrium provides ports for both C/OS-II and C/OS-III and recommends using one of these RTOS. In case you need to use another RTOS, this chapter will explain you how to port C/USB-Device to your RTOS.

Porting Overview

C/USB-Device uses some RTOS abstraction ports to interact with the RTOS. Instead of being a simple wrapper for common RTOS service functions (`TaskCreate()`, `SemaphorePost()`, etc...), those ports are in charge of allocating and managing all the OS resources needed. All the APIs are related to the C/USB-Device module feature that uses it. This offers you a better flexibility of implementation as you can decide which OS services can be used for each specific action. Table - Comparison between a wrapper and a features-oriented RTOS port in the *Porting Overview* page gives an example of comparison between a simple RTOS functions wrapper port and a features-oriented RTOS port.

Operation	Example of feature-oriented function (current implementation)	Equivalent function in a simple wrapper (not used)
Create a task	The stack is not in charge of creating tasks. This should be done in the RTOS abstraction layer within a `USBD_OS_Init()` function, for example.	`USBD_OS_TaskCreate()`. The stack would need to explicitly create the needed tasks and to manage them.
Create a signal for an endpoint	`USBD_OS_EP_SignalCreate()`. Another OS service than a typical Semaphore can be used.	`USBD_OS_SemCreate()`. The stack would need to explicitly choose the OS service to use.
Create a lock for an endpoint.	`USBD_OS_EP_LockCreate()`. Another OS service than a mutex can be used.	`USBD_OS_MutexCreate()`. The stack would need to explicitly choose the OS service to use.
Put a core event in a queue	`USBD_OS_CoreEventPut()`. If you prefer not using typical OS queues, you could still implement it using a chained list and a semaphore, for instance.	`USBD_OS_Q_Post()`. Again, the stack would need to explicitly choose the OS service to use.

Table - Comparison between a wrapper and a features-oriented RTOS port

Because of the features oriented RTOS port design, some C/USB-Device modules will need their own OS port. These modules are listed here:

- C/USB-Device core layer
- Audio Class
- Human Interface Device Class (HID)
- Mass Storage Class (MSC)
- Personal Healthcare Device Class (PHDC)

Moreover, all the demo applications for each USB class that Micrium provides interact with the RTOS. The demo applications do not benefit from an RTOS port. Therefore, if you plan to use them with an RTOS other than C/OS-II or C/OS-III, you will have to modify them.

Figure - µC/USB-Device architecture with RTOS interactions in the *Porting Overview* page summarizes the interactions between the different C/USB-Device modules and the RTOS.

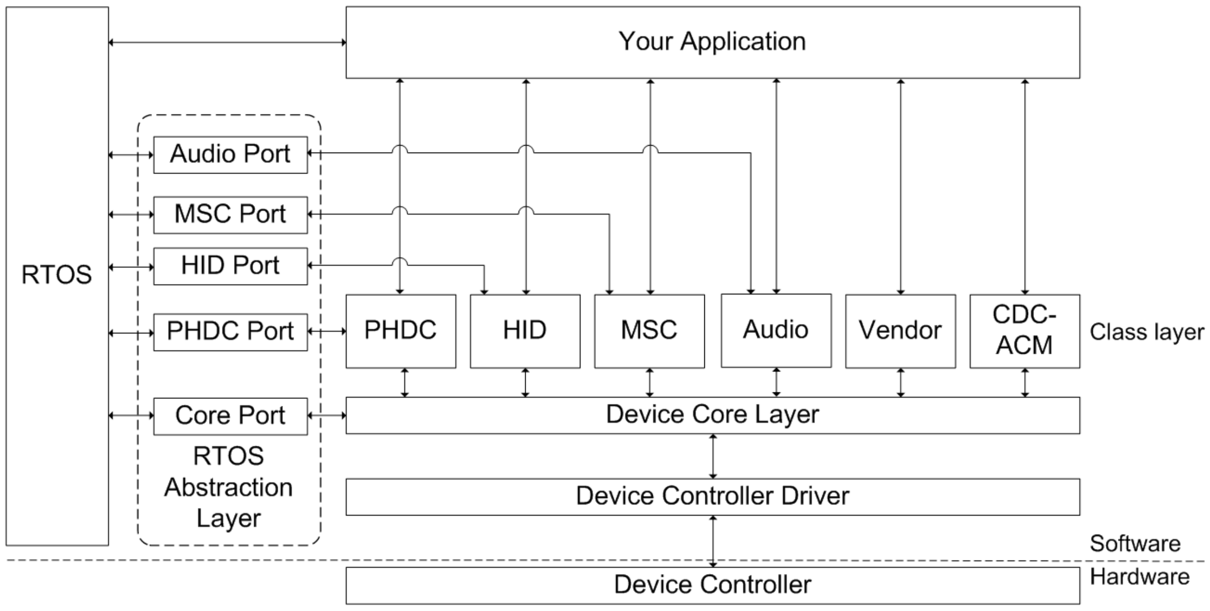


Figure - µC/USB-Device architecture with RTOS interactions

Porting Modules to an RTOS

Table - References to Port a Module to an RTOS in the *Porting Modules to an RTOS* page lists the section of this manual to which you should refer to for an explanation on how to port C/USB-Device modules to an RTOS.

Module	Refer to...
Core layer	Porting the Core Layer to an RTOS
Audio Class	Porting the Audio Class to an RTOS
HID Class	Porting the HID Class to an RTOS
MSC	Porting MSC to an RTOS
PHDC	Porting PHDC to an RTOS

Table - References to Port a Module to an RTOS

Core Layer RTOS Model

The core layer of C/USB-Device needs an RTOS for three purposes:

- Signal the completion of synchronous transfers.
- Manage core events.
- Manage debug events (optional).

Core Events Management

For proper operation, the core layer needs an OS task that will manage the core events. For more information on the purpose of this task or on what a core event is, refer to the Task Model page. The core events must be queued in a data structure and be processed by the core. This allows the core to process the events in a task context instead of in an ISR context, as most of the events will be raised by the device driver’s ISR. The core task also needs to be informed when a new event is queued. Figure - Core events management within RTOS port in the *Core Layer RTOS Model* page describes the core events management within the RTOS port.

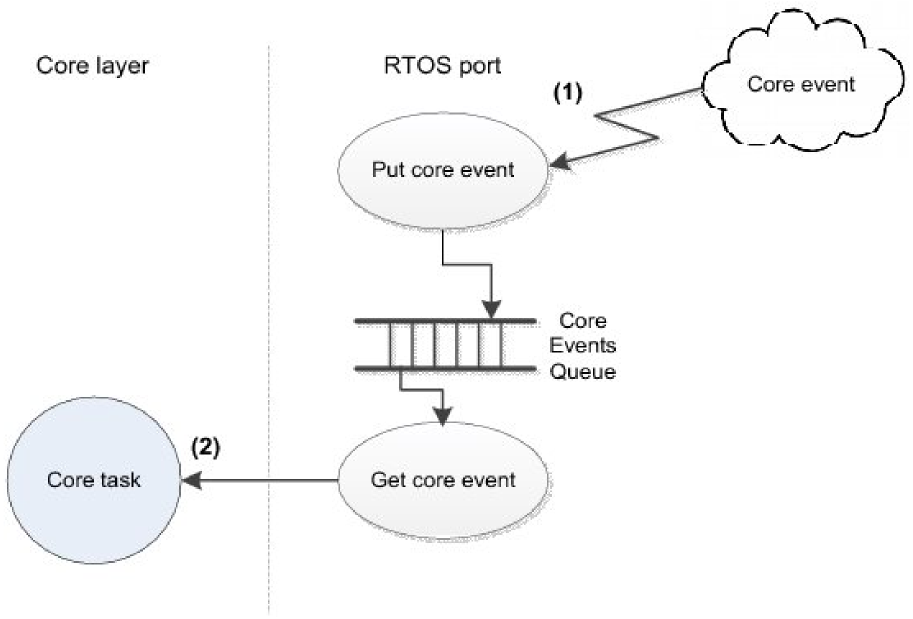


Figure - Core events management within RTOS port

(1) A core event is added to the queue.

(2) The core task of the core layer pends on the queue. Whenever an event is added, the core task is resumed to process it.

Debug Events Management

The core layer of C/USB-Device offers an optional feature to do tracing and debugging. For more information on this feature, see the Debug and Trace page. This feature requires an OS task. For more information on the purpose of this task or on debug events, refer to the Task Model page. The behavior of this task is similar to the core task described in the Core Events Management section. The difference is that the RTOS port does not need to manage the queue, as it is handled within the core layer. The RTOS port only needs to provide a signal that will inform of a debug event insertion.

Synchronous Transfer Completion Signals

The core layer needs a way to signal the application about the synchronous transfer completion. The core will need one signal per endpoint. The RTOS resources usually used for this signal is a semaphore. Figure - Synchronous transfer completion notification in the *Core Layer RTOS Model* page describes a synchronous transfer completion notification.

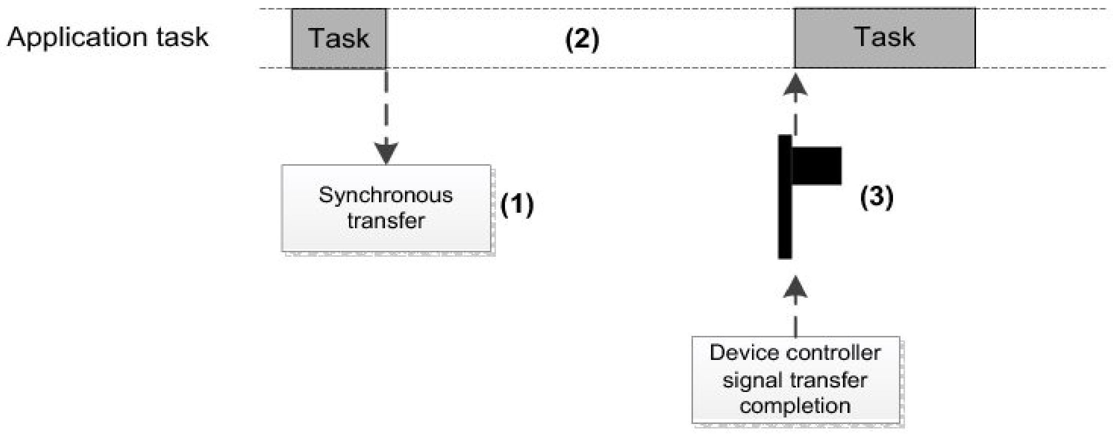


Figure - Synchronous transfer completion notification

(1) Application task calls a synchronous transfer function.

(2) While the transfer is in progress, the application task pends on the transfer completion signal.

(3) Once the transfer is completed, the core will post the transfer completion signal which will resume the application task.

Porting the Core Layer to an RTOS

The core RTOS port is located in a separate file named `usbd_os.c`. A template file can be found in the following folder:

```
\Micrium\Software\uC-USB-Device-V4\OS\Template
```

Table - Core OS port API summary in the *Porting the Core Layer to an RTOS* page summarizes all the functions that need to be implemented in the RTOS port file. For more information on how these functions should be implemented, refer to the Core Layer RTOS Model page and to the Core OS Functions reference.

Function name	Operation
`USBD_OS_Init()`	Initializes all internal members / tasks.
`USBD_OS_EP_SignalCreate()`	Creates OS signal used to synchronize synchronous transfers.
`USBD_OS_EP_SignalDel()`	Deletes OS signal used to synchronize synchronous transfers.
`USBD_OS_EP_SignalPend()`	Pends on OS signal used to synchronize synchronous transfers.
`USBD_OS_EP_SignalAbort()`	Aborts OS signal used to synchronize synchronous transfers.
`USBD_OS_EP_SignalPost()`	Posts OS signal used to synchronize synchronous transfers.
`USBD_OS_EP_LockCreate()`	Creates OS lock used to lock endpoint.
`USBD_OS_EP_LockDel()`	Deletes OS lock used to lock endpoint.
`USBD_OS_EP_LockAcquire()`	Acquires OS lock used to lock endpoint.
`USBD_OS_EP_LockRelease()`	Releases OS lock used to lock endpoint.
`USBD_OS_DbgEventRdy()`	Posts signal used to resume debug task.
`USBD_OS_DbgEventWait()`	Pends on signal used to resume debug task.
`USBD_OS_CoreEventGet()`	Retrieves the next core event to process.
`USBD_OS_CoreEventPut()`	Adds a core event to be processed by the core.
`USBD_OS_DlyMs()`	Delays a task for a number of milliseconds.

Table - Core OS port API summary

Note that you must declare at least one task for the core events management within your RTOS port. This task should simply call the core function `USBD_CoreTaskHandler` in an infinite loop. Furthermore, if you plan using the debugging feature, you must also create a task for this purpose. This task should simply call the core function `USBD_DbgTaskHandler` in an infinite loop. Listing - Core task and debug task typical implementation in the *Porting the Core Layer to an RTOS* page shows how these two task functions body should be implemented.

```
static  void  USBD_OS_CoreTask (void  *p_arg)
{
    (void)&p_arg;

    while (DEF_ON) {
        USBD_CoreTaskHandler();
    }
}

static  void  USBD_OS_TraceTask (void  *p_arg)
{
    (void)&p_arg;

    while (DEF_ON) {
        USBD_DbgTaskHandler();
    }
}
```

Listing - Core task and debug task typical implementation

Test and Validation of uC-USB-Device

This page gives details about the various tests done on the µC/USB-Device stack.

Before being released, the µC/USB-Device stack undergoes a series of test, to make sure that it respects the USB 2.0 specification. This page describes the tests that the Core, Classes and USB Device Drivers must pass before they are each released and a small description of every test.

List of Tests

Test	USB 2.0 Command Verifier Chapter 9	USB 2.0 Command Verifier Class-Specific Tests	Class Demo Application(s)	Other Tests
Core	Yes	All available classes	All available classes applications	Control Endpoint Transfer Test Zero-Length Packet Test
Audio Class	Yes	N/A	Microphone-only application Loopback application	If audio codec driver is available for the platform, a typical usage test is performed.
CDC-ACM	Yes	N/A	Serial Terminal application	N/A
HID Class	Yes	Yes	Mouse application Read-Write application	N/A
MSC	Yes	Yes	RAMDisk application	N/A
PHDC	Yes	Yes	PHDC example application	N/A
Vendor Class	Yes	N/A	Synchronous Vendor example application Asynchronous Vendor example application	N/A
Device Driver	Yes	All available classes	All available classes applications	Control Endpoint Transfer Test Zero-Length Packet Test

Table - List of tests for µC/USB-Device and its components

Description

USB 2.0 Command Verifier

The USB 2.0 Command Verifier (USBCV) is a tool created by the USB Implementer Forum (USB-IF) to test the compliance of a given device to the USB 2.0 Specification. A USB device must successfully pass all of these tests in order to obtain the USB certification.

Chapter 9

This series of test exercises the control endpoints transfers paths and the control transfers sequence (Setup, Data, Status). It also makes sure that the device handles correctly the standard requests and that the standard descriptors obtained are correctly built.

Class-Specific Tests

USBCV also implements tests for some of the USB classes available with µC/USB-Device.Theses classes are: HID Class, MSC and PHDC.

For the HID class, USBCV tests the validity of the sent and received descriptors and the 'Set Idle' Class Request.

For MSC, the descriptors, the class requests and the protocol are tested. USBCV also performs a series of test cases, including error recovery, valid and invalid data transfers, faulty transfer sequence, etc and monitors the device's response to these test cases. That is, it makes sure that the device succeeds where it should and fails and recovers when required.

In the case of PHDC, USBCV will test the validity of the descriptors and the class and standard requests. It will also test the reliability and latency of the transfers, as specified in the PHDC specification. USBCV will also execute tests related to the protocol, making sure that the device answers correctly to the various requests and stalls whenever required.

Classes Demo Application

Audio Class

The audio class is tested with two different demo applications. The simplest one is a microphone-only example that transmits a pre-selected waveform to the host PC. This exercises the class requests, including the Set Sampling Frequency, Set Volume, Mute/Un-mute and the Start/Stop Streaming Interface. It also tests the isochronous transmit path and the queuing mechanism. The other demo application is a loopback that simply echoes back to the host PC what it just received from it. It tests both isochronous transfer paths (transmit and receive) and the queuing mechanism. It also tests the descriptors and standard requests related to the Audio class.

CDC-ACM

The CDC-ACM test is a terminal-based application that echoes characters back to the host PC. Using a serial terminal on the host PC, it is possible to exchange data with the device. This tests the correct handling of various class/subclass requests and the Bulk synchronous transfer IN and OUT path.

HID Class

The HID class can be tested by two different applications. The first one is a simple mouse emulator. It sends data to the host PC as if it was a simple mouse moving back and forth every 1ms. This test allows to make sure the interrupt asynchronous IN path works correctly and that the descriptors, reports and class requests are in compliance with the HID class specification. The other HID demo application is composed of two tasks: one 'read' and one 'write' task. It allows the device to exchange data with the host PC as a custom HID device would. It exercises the synchronous interrupt IN and OUT transfer paths.

MSC

The MSC demo application consists in a RAM-based USB key. It acts exactly as a USB flash drive would, except that its content is volatile and will not be kept if it loses power. This allows to test the bulk transfers paths (IN and OUT), the composition of the descriptors, the compliance with the MSC protocol and the class requests. It also allows to test the interaction between a MSC device and various host operating systems.

PHDC

The PHDC demo application is a basic console application displaying various statistics of the platform (CPU Usage and Timer, for example). It tests the descriptors, the various class requests and the bulk IN and OUT and interrupt IN transfers paths. It also allows to experiment with the various QoS available.

Vendor Class

The Vendor class demo application exchanges data between the host PC and the device by following a known protocol. This exercises the bulk IN and OUT synchronous and asynchronous transfers paths and the correct handling of large transfers. It can also be used to test vendor class requests.

Other Tests

Audio Typical Usage Test

If an audio codec and its associated driver are available, they will be tested by the following typical applications: microphone-only, speaker-only and headset (microphone and speaker). Class requests supported by the audio codec and its driver will also be tested.

MSC Storage Test

This test is the same than the RAM-based one, except another storage medium is used.

Control Endpoint Transfer Test

This custom test sends and receives data by the default control endpoint. It can execute larger transfers than what is expected during a typical enumeration, testing the case when several transactions are required for a single transfer. Also, since control OUT transfers are infrequent during enumeration and basic usage, this tests them more thoroughly.

Zero-Length Packet Test

This custom test verifies the correct handling of zero-length packets when execute transfers of unknown size. For example, if the device expects up to 3000 bytes and that it only receives 1024 bytes, which is a multiple of the maximum packet size (8, 16, 32, 64 or 512 (high-speed only) bytes), the host needs to send a zero-length packet to indicate that the transfer is completed and the device must be able to accept and interpret correctly this zero-length packet.

Troubleshooting

This page contains information about everything related to troubleshooting and debugging tools.

It contains information about:

- statistics and the various way they can be interpreted;
- error codes significations and solutions to solve them.

Built-in Statistics

This page details the way to interpret the various statistics that can be accessed within µC/USB-Device.

Configuration

In `usbd_cfg.h`, `USBD_CFG_DBG_STATS_EN` must be set to `DEF_ENABLED`.

By default, constant `USBD_CFG_DBG_STATS_CNT_TYPE` is set to `CPU_INT08U`, meaning that the counter will overflow after counting 256 events. This constant can be set to `CPU_INT16U` or `CPU_INT32U` to increase the overflow limit.

It is recommended that the statistics feature is turned OFF for 'release' code, since a good amount of RAM is used to keep the statistics counters.

Accessing statistics

The statistics can be accessed easily from any scope (application, class, core, driver, etc), simply by monitoring the variables `USBD_DbgStatsDevTbl[]` and `USBD_DbgStatsEP_Tbl[]`. This can usually be done by using a regular debugger.

Content

The statistics are split in two levels: device level and endpoint level. The following tables gives information about the fields of each of these structures. Please note that even though each endpoint has a complete statistics structure associated with it, since an endpoint only works in on direction, only the `Rx` or `Tx` fields will be used for a given endpoint. That is, if the endpoint is an `IN` endpoint, only the `Tx` fields will be modified. If the endpoint is an `OUT` endpoint, the `Rx` fields will be the only ones modified.

Device Level

The table `USBD_DbgStatsDevTbl[]` contains `USBD_CFG_MAX_NBR_DEV` number of `USBD_DBG_STATS_DEV` struct, one for each device. The `device number` is used as an index to access a specific device's statistics.

Field Name	Explanation	Relates to...
`DevNbr`	Number of the device, starting at 0.	The device number depends of the order in which the device is added using `USBD_DevAdd`.
`DevResetEventNbr`	Number of reset event on the bus.	Should be 2 after minimal enumeration.
`DevSuspendEventNbr`	Number of suspend event on the bus.	Should be 2 after minimal enumeration.
`DevResumeEventNbr`	Number of resume event on the bus.	Should be 1 after minimal enumeration.
`DevConnEventNbr`	Number of connection event of the device.	Varies.
`DevDisconnEventNbr`	Number of disconnection event of the device.	Varies.
`DevSetupEventNbr`	Number of SETUP packets the device received.	Should be 10-11 after minimal enumeration, depending if Windows requests its OS descriptor or not.
`StdReqDevNbr`	Number of standard requests having 'device' as a recipient.	Should be 10-11 after minimal enumeration, depending if Windows requests its OS descriptor or not and if it fails or not.
`StdReqDevStallNbr`	Number of standard requests having 'device' as a recipient that failed to be processed.	Should normally be equal to 0. It can be 1, if Windows requests its OS descriptor and it fails (or `USBD_CFG_MS_OS_DESC_EN` is set to `DEF_DISABLED`).
`StdReqIF_Nbr`	Number of standard requests having 'interface' as a recipient.	Should be 0 after minimal enumeration.
`StdReqIF_StallNbr`	Number of standard requests having 'interface' as a recipient that failed to be processed.	Should normally be equal to 0.
`StdReqEP_Nbr`	Number of standard requests having 'endpoint' as a recipient.	Should be 0 after minimal enumeration.
`StdReqEP_StallNbr`	Number of standard requests having 'endpoint' as a recipient that failed to be processed.	Should normally be equal to 0.
`StdReqClassNbr`	Number of standard requests having a class as a recipient.	Should be 0 after minimal enumeration.
`StdReqClassStallNbr`	Number of standard requests having a class as a recipient that failed to be processed.	Should normally be equal to 0.
`StdReqSetAddrNbr`	Number of `SET_ADDRESS` standard request the device received.	Should be equal to 1 after a successful enumeration.
`StdReqSetCfgNbr`	Number of `SET_CONFIGURATION` standard request the device received.	Should be equal to 1 after a successful enumeration.
`CtrlRxSyncExecNbr`	Number of synchronous receive operation started on a control endpoint type.	Varies with usage. Used throughout enumeration. Should be 0 after minimal enumeration.

`CtrlRxSyncSuccessNbr`	Number of synchronous receive operation on a control endpoint type that completed successfully.	Should be equal to `CtrlRxSyncExecNbr`.
`CtrlTxSyncExecNbr`	Number of synchronous transmit operation started on a control endpoint type.	Varies with usage. Used throughout enumeration. Should be 9 after minimal enumeration.
`CtrlTxSyncSuccessNbr`	Number of synchronous transmit operation on a control endpoint type that completed successfully.	Should be equal to `CtrlTxSyncExecNbr`.
`CtrlRxStatusExecNbr`	Number of status packets attempted to be received from the host.	Varies with usage. Used throughout enumeration. Should be 9 after minimal enumeration.
`CtrlRxStatusSuccessNbr`	Number of status packets successfully received from the host	Should be equal to `CtrlRxStatusExecNbr`.
`CtrlTxStatusExecNbr`	Number of status packets attempted to be sent to the host.	Varies with usage. Used throughout enumeration. Should be 1 after minimal enumeration.
`CtrlTxStatusSuccessNbr`	Number of status packets successfully sent to the host	Should be equal to `CtrlTxStatusExecNbr`.
`BulkRxSyncExecNbr`	Number of synchronous receive operation started on a bulk endpoint type.	Varies with usage. Used by CDC, MSC, PHDC and vendor class synchronous demo.
`BulkRxSyncSuccessNbr`	Number of synchronous receive operation on a bulk endpoint type that completed successfully.	Should be equal to `BulkRxSyncExecNbr`.
`BulkTxSyncExecNbr`	Number of synchronous transmit operation started on a bulk endpoint type.	Varies with usage. Used by CDC, MSC, PHDC and vendor class synchronous demo.
`BulkTxSyncSuccessNbr`	Number of synchronous transmit operation on a bulk endpoint type that completed successfully.	Should be equal to `BulkTxSyncExecNbr`.
`IntrRxSyncExecNbr`	Number of synchronous receive operation started on an interrupt endpoint type.	Varies with usage. Used by HID class read/write demo and vendor class synchronous demo.
`IntrRxSyncSuccessNbr`	Number of synchronous receive operation on an interrupt endpoint type that completed successfully.	Should be equal to `IntrRxSyncExecNbr`.
`IntrTxSyncExecNbr`	Number of synchronous transmit operation started on an interrupt endpoint type.	Varies with usage. Used by PHDC and vendor class synchronous demo.
`IntrTxSyncSuccessNbr`	Number of synchronous transmit operation on an interrupt endpoint type that completed successfully.	Should be equal to `IntrTxSyncExecNbr`.
`BulkRxAsyncExecNbr`	Number of asynchronous receive operation started on a bulk endpoint type.	Varies with usage, used by vendor class asynchronous demo.
`BulkRxAsyncSuccessNbr`	Number of asynchronous receive operation on a bulk endpoint type that completed successfully.	Should be equal to `BulkRxAsyncExecNbr`.

`BulkTxAsyncExecNbr`	Number of asynchronous transmit operation started on a bulk endpoint type.	Varies with usage, used by vendor class asynchronous demo.
`BulkTxAsyncSuccessNbr`	Number of asynchronous transmit operation on a bulk endpoint type that completed successfully.	Should be equal to `BulkTxAsyncExecNbr`.
`IntrRxAsyncExecNbr`	Number of asynchronous receive operation started on an interrupt endpoint type.	Varies with usage, used by vendor class asynchronous demo.
`IntrRxAsyncSuccessNbr`	Number of asynchronous receive operation on an interrupt endpoint type that completed successfully.	Should be equal to `IntrRxAsyncExecNbr`.
`IntrTxAsyncExecNbr`	Number of asynchronous transmit operation started on an interrupt endpoint type.	Varies with usage, used by CDC, HID class mouse and read/write demo and in vendor class asynchronous demo.
`IntrTxAsyncSuccessNbr`	Number of asynchronous transmit operation on an interrupt endpoint type that completed successfully.	Should be equal to `IntrTxAsyncExecNbr`.
`IsocRxAsyncExecNbr`	Number of asynchronous receive operation started on an isochronous endpoint type.	Varies with usage, used by audio class when playback is enabled.
`IsocRxAsyncSuccessNbr`	Number of asynchronous receive operation on an isochronous endpoint type that completed successfully.	Should be equal to `IsocRxAsyncExecNbr`.
`IsocTxAsyncExecNbr`	Number of asynchronous transmit operation started on an isochronous endpoint type.	Varies with usage, used by audio class when record is enabled.
`IsocTxAsyncSuccessNbr`	Number of asynchronous transmit operation on an isochronous endpoint type that completed successfully.	Should be equal to `IsocTxAsyncExecNbr`.

A minimal enumeration is considered to be a successful enumeration without any classes enabled.

Endpoint Level

The table `USBD_DbgStatsEP_Tbl[]` contains `USBD_CFG_MAX_NBR_DEV` * `USBD_CFG_MAX_NBR_EP_OPEN` number of `USBD_DBG_STATS_EP` struct, one for each potentially opened endpoint of each device. The `device number` and the endpoint's `index` are used as indexes to access a specific endpoint's statistics. It is also possible to simply browse the content of the `USBD_DBG_STATS_EP` struct to find the required endpoint address.

Field Name	Explanation	Relates to...

`Addr`	Address of the endpoint. The statistics of a given endpoint are kept if it is closed and then re-opened, if it uses the same endpoint structure. Otherwise, the statistics are reset when the endpoint is opened.	
`EP_OpenNbr`	Number of times the endpoint was opened successfully.	Should be equal to 2 after minimal enumeration (the endpoint is closed and re-opened upon device reset).
`EP_AbortExecNbr`	Number of times an abort operation has been started.	Should be equal to 0.
`EP_AbortSuccessNbr`	Number of times an abort operation has completed successfully.	Should be equal to `EP_AbortExecNbr`.
`EP_CloseExecNbr`	Number of times a close operation has been started.	Should be equal to 1 after minimal enumeration (the endpoint is closed upon device reset).
`EP_CloseSuccessNbr`	Number of times a close operation has completed successfully.	Should be equal to `EP_CloseExecNbr`.
`RxSyncExecNbr`	Number of times a synchronous receive operation has been started.	Should be equal to 0 after minimal enumeration.
`RxSyncSuccessNbr`	Number of times a synchronous receive operation has completed successfully.	Should be equal to `RxSyncExecNbr`.
`RxSyncTimeoutErrNbr`	Number of times a synchronous receive operation has timed out.	Varies with the type of application and transfer used, whether transfers are blocking or non-blocking, the protocol used by the application, etc.
`RxAsyncExecNbr`	Number of times an asynchronous receive operation has been started.	Should be equal to 0 after minimal enumeration.
`RxAsyncSuccessNbr`	Number of times an asynchronous receive operation has completed successfully.	Should be equal to `RxAsyncExecNbr`. At this point, the receive operation has been successfully signaled to the USB-Device core. It does not mean that the whole transfer has completed.
`RxZLP_ExecNbr`	Number of times a zero-length packet receive operation has been started.	Should be equal to 9 after minimal enumeration.
`RxZLP_SuccessNbr`	Number of times a zero-length packet receive operation has completed successfully.	Should be equal to `RxZLP_ExecNbr`.
`TxSyncExecNbr`	Number of times a synchronous transmit operation has been started.	Should be equal to 9 after minimal enumeration.
`TxSyncSuccessNbr`	Number of times a synchronous transmit operation has completed successfully.	Should be equal to `TxSyncExecNbr`.
`TxSyncTimeoutErrNbr`	Number of times a synchronous transmit operation has timed out.	Varies with the type of application and transfer used, whether transfers are blocking or non-blocking, the protocol used by the application, etc.
`TxAsyncExecNbr`	Number of times an asynchronous transmit operation has been started.	Should be equal to 0 after minimal enumeration.

`TxAsyncSuccessNbr`	Number of times an asynchronous transmit operation has completed successfully.	Should be equal to `TxAsyncExecNbr`. At this point, the transmit operation has been successfully signaled to the USB-Device core. It does not mean that the whole transfer has completed.
`TxZLP_ExecNbr`	Number of times a zero-length packet transmit operation has been started.	Should be equal to 1 after minimal enumeration.
`TxZLP_SuccessNbr`	Number of times a zero-length packet transmit operation has completed successfully.	Should be equal to `TxZLP_ExecNbr`.
`DrvRxStartNbr`	Number of times the driver's `EP_RxStart()` function was called.	Should be equal to 9 after minimal enumeration.
`DrvRxStartSuccessNbr`	Number of times the driver's `EP_RxStart()` function was called successfully.	Should be equal to `DrvRxStartNbr`.
`DrvRxNbr`	Number of times the driver's `EP_Rx()` function was called.	Should be equal to 0 after minimal enumeration.
`DrvRxSuccessNbr`	Number of times the driver's `EP_Rx()` function was called successfully.	Should be equal to `DrvRxNbr`.
`DrvRxZLP_Nbr`	Number of times the driver's `EP_RxZLP()` function was called.	Should be equal to 9 after minimal enumeration.
`DrvRxZLP_SuccessNbr`	Number of times the driver's `EP_RxZLP()` function was called successfully.	Should be equal to `DrvRxZLP_Nbr`.
`RxCmplNbr`	Number of times the driver has called `USBD_EP_RxCmpl()`.	Should be equal to 9 after minimal enumeration.
`RxCmplErrNbr`	Number of times the driver's call to `USBD_EP_RxCmpl` failed.	Should be equal to 0.
`DrvTxNbr`	Number of times the driver's `EP_Tx()` function was called.	Should be equal to 9 after minimal enumeration.
`DrvTxSuccessNbr`	Number of times the driver's `EP_Tx()` function was called successfully.	Should be equal to `DrvTxNbr`.
`DrvTxStartNbr`	Number of times the driver's `EP_TxStart()` function was called.	Should be equal to 9 after minimal enumeration.
`DrvTxStartSuccessNbr`	Number of times the driver's `EP_TxStart()` function was called successfully.	Should be equal to `DrvTxStartNbr`.
`DrvTxZLP_Nbr`	Number of times the driver's `EP_TxZLP()` function was called.	Should be equal to 1 after minimal enumeration.
`DrvTxZLP_SuccessNbr`	Number of times the driver's `EP_TxZLP()` function was called successfully.	Should be equal to `DrvTxZLP_Nbr`.
`TxCmplNbr`	Number of times the driver has called `USBD_EP_TxCmpl()`.	Should be equal to 10 after minimal enumeration.
`TxCmplErrNbr`	Number of times the driver's call to `USBD_EP_TxCmpl()` failed.	Should be equal to 0.

Error Codes and Solutions

This page lists the various error codes present in µC/USB-Device, their potential causes and some tips to solve the issues they are indicating.

Categories	Value	Error Code	Potential Cause(s)	Solution(s)
Generic Errors	0	`USBD_ERR_NONE`	No error, nothing to do.	None.
	1	`USBD_ERR_FAIL`	Generic error occurred.	Varies depending where the error occurred.
	2	`USBD_ERR_RX`	Generic error occurred during a 'Rx' transfer.	Varies depending where the error occurred.
	3	`USBD_ERR_TX`	Generic error occurred during a 'Tx' transfer.	Varies depending where the error occurred.
	4	`USBD_ERR_ALLOC`	Generic allocation error.	The memory segment (or the heap, from uC/LIB) from which the memory is allocated does not have enough space remaining. Try increasing the size of the memory segment or the heap, if possible. If not, try adjusting the configuration values in `usbd_cfg.h` or `app_usbd_cfg.h` to better fit the needs of the application.
	5	`USBD_ERR_NULL_PTR`	Null pointer passed as an argument.	See where error occurred and what was the parameter checked.
	6	`USBD_ERR_INVALID_ARG`	An invalid argument has been passed to the function.	See where error occurred and what was the parameter checked.
	7	`USBD_ERR_INVALID_CLASS_STATE`	The class is in an invalid state.	See where error occurred and what is the current state of the class.
Device Errors	100	`USBD_ERR_DEV_ALLOC`	Tried to allocate more devices than the configured value allows.	`USBD_CFG_MAX_NBR_DEV` must be increased. This define can be found in `usbd_cfg.h`.
	101	`USBD_ERR_DEV_INVALID_NBR`	Unable to obtain device or driver reference based on specified `dev_nbr`.	Make sure `dev_nbr` is correct.

	102	`USBD_ERR_DEV_INVALID_STATE`	Device is in an incorrect state (None, Init, Attached, Default, Addressed, Configured or Suspended) to execute the requested operation.	Verify what state the device is currently in and see why it cannot execute the requested operation or why it is in this state.
	103	`USBD_ERR_DEV_INVALID_SPD`	High-speed operation attempted on a driver/controller that does not support high-speed operations.	If the controller used support high-speed operations, make sure the speed declared in the driver configuration (USBD_DrvCfg_xxxx) is correct. If the controller used does not support high-speed operations, high-speed operations cannot be executed.
	104	`USBD_ERR_DEV_UNAVAIL_FEAT`	The feature requested is unavailable in the module used.	See where/why the error occurred.
Configuration Errors	200	`USBD_ERR_CFG_ALLOC`	Tried to allocate more USB configuration than the configured value allows.	`USBD_CFG_MAX_NBR_CFG` must be increased. This define can be found in `usbd_cfg.h`.
	201	`USBD_ERR_CFG_INVALID_NBR`	Unable to obtain configuration reference based on `cfg_nbr` or `cfg_nbr` passed is invalid.	Make sure `cfg_nbr` is correct.
	202	`USBD_ERR_CFG_INVALID_MAX_PWR`	`max_pwr` parameter is invalid.	Adjust `max_pwr` value.
	203	`USBD_ERR_CFG_SET_FAIL`	Call to driver's `CfgSet` failed.	See each driver's `CfgSet()` function for more details.
Interface Errors	300	`USBD_ERR_IF_ALLOC`	Tried to allocate more USB interfaces than the configured value allows.	`USBD_CFG_MAX_NBR_IF` must be increased. This define can be found in `usbd_cfg.h`.
	301	`USBD_ERR_IF_INVALID_NBR`	Unable to obtain interface reference based on `if_nbr`.	Make sure `if_nbr` is correct.
	302	`USBD_ERR_IF_ALT_ALLOC`	Tried to allocate more USB alternate interfaces than the configured value allows.	`USBD_CFG_MAX_NBR_IF_ALT` must be increased. This define can be found in `usbd_cfg.h`.
	303	`USBD_ERR_IF_ALT_INVALID_NBR`	Unable to obtain interface reference based on `if_alt_nbr`.	Make sure `if_alt_nbr` is correct.

	304	`USBD_ERR_IF_GRP_ALLOC`	Tried to allocate more interface groups than the configured value allows.	`USBD_CFG_MAX_NBR_IF_GRP` must be increased. This define can be found in `usbd_cfg.h`.
	305	`USBD_ERR_IF_GRP_NBR_IN_USE`	Interface is already associated with an interface group.	Cannot associate an interface to more than one group.
Endpoint Errors	400	`USBD_ERR_EP_ALLOC`	Tried to allocate more endpoints than the configured value allows.	`USBD_CFG_MAX_NBR_EP_DESC` must be increased. This define can be found in `usbd_cfg.h`.
	401	`USBD_ERR_EP_INVALID_ADDR`	Unable to obtain endpoint reference based on `ep_addr`.	Make sure `ep_addr` and `dev_nbr` are correct.
	402	`USBD_ERR_EP_INVALID_STATE`	Endpoint is in an invalid state (Close, Open, Stall) to execute requested operation.	Verify what state the endpoint is currently in and see why it cannot execute the requested operation or why it is in this state.
	403	`USBD_ERR_EP_INVALID_TYPE`	Endpoint type (Control, Bulk, Interrupt, Isochronous) is invalid.	Make sure the endpoint type matches the type of endpoint of the function called.
	404	`USBD_ERR_EP_NONE_AVAIL`	Requested endpoint is unavailable.	Try to adjust the `USBD_CFG_MAX_NBR_EP_OPEN` (in `usbd_cfg.h`) constant or see if the driver used supports the endpoint type requested and/or has enough endpoints to open the requested one.
	405	`USBD_ERR_EP_ABORT`	Transfer has been aborted, or error when aborting.	
	406	`USBD_ERR_EP_STALL`	Unable to execute correctly the stall operation requested.	See driver's `EP_Stall()` function for more details.
	407	`USBD_ERR_EP_IO_PENDING`	A transfer is already in progress on the specified endpoint and the core cannot queue the next transfer after it.	Avoid executing synchronous transfers on busy endpoints or trying to queue asynchronous transfers after synchronous ones.
	408	`USBD_ERR_EP_QUEUING`	Unable to queue URB.	Too much asynchronous transfers are queued at the same time, wait for a transfer to finish before submitting another one.
OS Layer Errors	500	`USBD_ERR_OS_INIT_FAIL`	OS layer initialization failed.	See OS User's Manual and OS layer where error occurred for more details.

	501	`USBD_ERR_OS_SIGNAL_CREATE`	OS signal creation failed.	See OS User's Manual and OS layer where error occurred for more details.
	502	`USBD_ERR_OS_FAIL`	OS layer operation failed.	See OS User's Manual and OS layer where error occurred for more details.
	503	`USBD_ERR_OS_TIMEOUT`	OS pend/lock operation timed-out.	See OS User's Manual and OS layer where error occurred for more details.
	504	`USBD_ERR_OS_ABORT`	OS pend/lock operation was aborted.	See OS User's Manual and OS layer where error occurred for more details.
	505	`USBD_ERR_OS_DEL`	OS layer deletion failed.	See OS User's Manual and OS layer where error occurred for more details.
Device Driver Errors	700	`USBD_ERR_DRV_BUF_OVERFLOW`	Driver indicated that buffer overflowed.	See device driver for more details.
	701	`USBD_ERR_DRV_INVALID_PKT`	Driver indicated an invalid packet has been received.	See device driver for more details.
Generic Class Errors	1000	`USBD_ERR_CLASS_INVALID_NBR`	`class_nbr` or `sublcass_nbr` parameter is invalid.	Check the value of `class_nbr` or `subclass_nbr` where the error occurred.
	1001	`USBD_ERR_CLASS_XFER_IN_PROGRESS`	A transfer is already in progress on the endpoint used by the class.	Wait for the transfer to completed before executing another one.
Audio Class Errors	1100	`USBD_ERR_AUDIO_INSTANCE_ALLOC`	Tried to allocate more audio class instances than configured values allow.	Depending on where the error occurred, either `USBD_AUDIO_CFG_MAX_NBR_CFG` or `USBD_AUDIO_CFG_MAX_NBR_AIC` must be increased. These defines can be found in `usbd_cfg.h`.
	1101	`USBD_ERR_AUDIO_AS_IF_ALLOC`	Tried to allocate more audio streaming interfaces than configured values allow.	Depending on where the error occurred, either `USBD_AUDIO_CFG_MAX_NBR_CFG`, `USBD_AUDIO_CFG_MAX_NBR_AIC`, `USBD_AUDIO_CFG_MAX_NBR_AS_IF` or `USBD_AUDIO_CFG_MAX_NBR_IF_ALT` must be increased. These defines can be found in `usbd_cfg.h`.
	1102	`USBD_ERR_AUDIO_IT_ALLOC`	Tried to allocate more input terminals than configured value allows.	`USBD_AUDIO_CFG_MAX_NBR_IT` must be increased. This define can be found `usbd_cfg.h`.
	1103	`USBD_ERR_AUDIO_OT_ALLOC`	Tried to allocate more output terminals than configured value allows.	`USBD_AUDIO_CFG_MAX_NBR_OT` must be increased. This define can be found `usbd_cfg.h`.

	1104	`USBD_ERR_AUDIO_FU_ALLOC`	Tried to allocate more feature units than configured value allows.	`USBD_AUDIO_CFG_MAX_NBR_FU` must be increased. This define can be found `usbd_cfg.h`.
	1105	`USBD_ERR_AUDIO_MU_ALLOC`	Tried to allocate more mixing units than configured value allows.	`USBD_AUDIO_CFG_MAX_NBR_MU` must be increased. This define can be found `usbd_cfg.h`.
	1106	`USBD_ERR_AUDIO_SU_ALLOC`	Tried to allocate more selector units than configured value allows.	`USBD_AUDIO_CFG_MAX_NBR_SU` must be increased. This define can be found `usbd_cfg.h`.
	1107	`USBD_ERR_AUDIO_REQ_INVALID_CTRL`	Unable to process class request, the `ctrl` field is invalid/not supported.	The audio class will stall the control endpoint to indicate to the host that the device does not support this type of request.
	1108	`USBD_ERR_AUDIO_REQ_INVALID_ATTRIB`	Unable to process class request, the `attrib` field is invalid/not supported.	The audio class will stall the control endpoint to indicate to the host that the device does not support this type of request.
	1109	`USBD_ERR_AUDIO_REQ_INVALID_RECIPIENT`	Unable to process class request, the `recipient` field is invalid/not supported.	The audio class will stall the control endpoint to indicate to the host that the device does not support this type of request.
	1110	`USBD_ERR_AUDIO_REQ`	Unable to process class request for any other reason.	The audio class will stall the control endpoint to indicate to the host that the device does not support this type of request.
	1111	`USBD_ERR_AUDIO_INVALID_SAMPLING_FRQ`	The requested sampling frequency is not supported.	See specific audio codec's code for setting sampling frequency.
	1112	`USBD_ERR_AUDIO_CODEC_INIT_FAILED`	Audio codec initialization failed.	See specific audio codec's code for initialization.
CDC Errors	1200	`USBD_ERR_CDC_INSTANCE_ALLOC`	Tried to allocate more CDC instances than configured values allow.	Depending on where the error occurred, either `USBD_CDC_CFG_MAX_NBR_DEV`, `USBD_CDC_CFG_MAX_NBR_CFG` or `USBD_CDC_CFG_MAX_NBR_DATA_IF` must be increased. These defines can be found in `usbd_cfg.h`.
	1201	`USBD_ERR_CDC_DATA_IF_ALLOC`	Tried to allocate more CDC data interfaces than configured values allow.	`USBD_CDC_CFG_MAX_NBR_DATA_IF` must be increased. This define can be found in `usbd_cfg.h`.

	1250	`USBD_ERR_CDC_SUBCLASS_INSTANCE_ALLOC`	Tried to allocate more instances of a given CDC subclass than configured values allow.	`USBD_ACM_SERIAL_CFG_MAX_NBR_DEV` must be increased. This define can be found in `usbd_cfg.h`.
HID Class Errors	1300	`USBD_ERR_HID_INSTANCE_ALLOC`	Tried to allocate more HID class instances than configured values allow.	Depending on where the error occurred, either `USBD_HID_CFG_MAX_NBR_DEV` or `USBD_HID_CFG_MAX_NBR_CFG` must be increased. These defines can be found in `usbd_cfg.h`.
	1301	`USBD_ERR_HID_REPORT_INVALID`	The format of the report descriptor given as parameter to `USBD_HID_Add()` is invalid.	See where exactly the error occurred in `USBD_HID_Report_Parse()` to have more details about the reason the parsing failed.
	1302	`USBD_ERR_HID_REPORT_ALLOC`	Failed to allocate internal data structure for report descriptor.	There can be a few reasons why this failed. You can try increasing `USBD_HID_CFG_MAX_NBR_REPORT_ID` in `usbd_cfg.h`, or see if an invalid parameter has been passed to function `USBD_HID_ReportID_Get()`.
	1303	`USBD_ERR_HID_REPORT_PUSH_POP_ALLOC`	Failed to allocate internal data structure for push-pop item.	`USBD_HID_CFG_MAX_NBR_REPORT_PUSHPOP` must be increased. This define can be found in `usbd_cfg.h`.
MSC Errors	1400	`USBD_ERR_MSC_INSTANCE_ALLOC`	Tried to allocate more MSC instances than configured values allow.	Depending on where the error occurred, either `USBD_MSC_CFG_MAX_NBR_DEV` or `USBD_MSC_CFG_MAX_NBR_CFG` must be increased. These defines can be found in `usbd_cfg.h`.
	1401	`USBD_ERR_MSC_INVALID_CBW`	Command Block Wrapper (CBW) received by the internal MSC task is invalid.	The CBW content contains an error or its length is incorrect. The MSC class will report to the host through the CSW that the SCSI command has failed and the host will take the proper action to continue.
	1402	`USBD_ERR_MSC_INVALID_DIR`	Mismatch between direction indicated by CBW and the SCSI command.	The MSC class will report to the host through the CSW that the SCSI command has failed and the host will take the proper recovery action.
	1403	`USBD_ERR_MSC_MAX_LUN_EXCEED`	No more logical unit can be added to the MSC class.	`USBD_MSC_CFG_MAX_LUN` must be increased. This define can be found in `usbd_cfg.h` .
	1404	`USBD_ERR_MSC_MAX_VEN_ID_LEN_EXCEED`	Vendor ID string associated to a logical unit is too long.	Shorten your vendor string to be less than or equal to 8 characters.

1405	`USBD_ERR_MSC_MAX_PROD_ID_LEN_EXCEED`	Product ID string associated to a logical unit is too long.	Shorten your vendor string to be less than or equal to 16 characters.
1406	`USBD_ERR_SCSI_UNSUPPORTED_CMD`	SCSI command not recognized.	The host has sent a SCSI command not supported by MSC (Refer to section SCSI Commands for supported SCSI commands). The MSC class will report to the host through the CSW that the SCSI command has failed. The host will take the proper action.
1407	`USBD_ERR_SCSI_MORE_DATA`	Read or write SCSI command requires more data to be read or written.	The MSC class will read more data from the storage medium to send it to the host or will wait for data from host to write it to the storage medium.
1408	`USBD_ERR_SCSI_LU_NOTRDY`	Logical unit not ready to perform any operations.	For any reason, the storage layer has returned that the logical unit is not ready to be accessed. The MSC class will report to the host through the CSW that the SCSI command has failed. The host may send periodically the TEST_UNIT_READY SCSI command until the logical unit is ready to be accessed.
1409	`USBD_ERR_SCSI_LU_NOTSUPPORTED`	Logical unit number not supported.	The storage layer reports that the logical unit number does not exist. The MSC class will report to the host through the CSW that the SCSI command has failed. The host should stop trying to access the logical unit number.
1410	`USBD_ERR_SCSI_LU_BUSY`	Logical unit number is busy with other operations.	For any reason, the storage layer has returned that the logical unit is occupied with an operation in progress. The MSC class will report to the host through the CSW that the SCSI command has failed. The host may send periodically the TEST_UNIT_READY SCSI command until the logical unit has finished its ongoing operation.
1411	`USBD_ERR_SCSI_LOG_BLOCK_ADDR`	Logical block address out of range when host asks the device to test one or more sectors.	The MSC class will report to the host through the CSW that the SCSI command has failed. The host should not try to access again this sector.

1412	`USBD_ERR_SCSI_MEDIUM_NOTPRESENT`	Removable storage medium is not present.	When an MSC device has a fixed storage medium, this one is always present. For MSC devices with a removable storage medium, upon connection to the PC, the medium may not be present. In that case, the MSC class will report to the host through the CSW that the SCSI command has failed. The host may send periodically the TEST_UNIT_READY SCSI command until the storage medium is inserted.
1413	`USBD_ERR_SCSI_MEDIUM_NOT_RDY_TO_RDY`	The storage medium is transitioning to the ready state.	The storage medium cannot accept yet to be accessed by the host because it changes its internal state. In that case, the storage layer returns this error code. The MSC class will report to the host through the CSW that the SCSI command has failed. The host may send periodically the TEST_UNIT_READY SCSI command until the storage medium has completed its transition to the ready state.
1414	`USBD_ERR_SCSI_MEDIUM_RDY_TO_NOT_RDY`	The storage medium is transitioning to the not ready state.	The storage medium won't accept anymore to be accessed by the host because it changes its internal state. In that case, the storage layer returns this error code. T he MSC class will report to the host through the CSW that the SCSI command has failed. The host may send periodically the TEST_UNIT_READY SCSI command until the storage medium is afresh in the ready state.
1415	`USBD_ERR_SCSI_LOCK`	Locking a storage medium has failed.	When the host accesses a storage medium, it becomes the only owner of this storage. No embedded file system application can access this storage. The ownership is guaranteed with a lock system. If the lock cannot be acquired, it means that an embedded file system application has the storage ownership. The MSC will report to the host through the CSW that the SCSI command has failed. The host should attempt again the SCSI command until the lock can be acquired.

	1416	`USBD_ERR_SCSI_LOCK_TIMEOUT`	Locking a storage medium has timeout.	If the lock is acquired, an embedded file system application has the storage ownership. The MSC class attempts acquiring the lock during a certain period of time. When this time period has elapsed, the lock attempt timeouts. The MSC will report to the host through the CSW that the SCSI command has failed. The host should attempt again the SCSI command until the lock can be acquired.
	1417	`USBD_ERR_SCSI_UNLOCK`	Unlocking the medium storage has failed.	The MSC class was not able to release the storage ownership. The MSC will report to the host through the CSW that the SCSI command has failed. The host should attempt again the SCSI command until the lock release succeeds.
PHDC Errors	1500	`USBD_ERR_PHDC_INSTANCE_ALLOC`	Tried to allocate more PHDC instances than configured values allow.	Depending on where the error occurred, either `USBD_PHDC_CFG_MAX_NBR_DEV` or `USBD_PHDC_CFG_MAX_NBR_CFG` must be increased. These defines can be found in `usbd_cfg.h`.
Vendor Errors	1600	`USBD_ERR_VENDOR_INSTANCE_ALLOC`	Tried to allocate more Vendor class instances than configured values allow.	Depending on where the error occurred, either `USBD_VENDOR_CFG_MAX_NBR_DEV` or `USBD_VENDOR_CFG_MAX_NBR_CFG` must be increased. These defines can be found in `usbd_cfg.h`.