

MCHPFSUSB Firmware User's Guide

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NOTES:

Preface

NOTICE TO CUSTOMERS

All documentation becomes dated, and this manual is no exception. Microchip tools and documentation are constantly evolving to meet customer needs, so some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our web site (www.microchip.com) to obtain the latest documentation available.

Documents are identified with a “DS” number. This number is located on the bottom of each page, in front of the page number. The numbering convention for the DS number is “DSXXXXA”, where “XXXX” is the document number and “A” is the revision level of the document.

For the most up-to-date information on development tools, see the MPLAB® IDE on-line help. Select the Help menu, and then Topics to open a list of available on-line help files.

INTRODUCTION

This document discusses the technical details and functionality of the MCHPFSUSB Firmware. It assumes that the programmer already: a) Knows how to write C programs; b) Knows how to use the MPLAB Integrated Development Environment (IDE); c) Understands the microcontroller data sheet for which the code is being written; d) Understands some basic USB concepts, such as those covered in chapters 5, 8 and 9 in the official USB 2.0 specifications. Items discussed in this chapter include:

- About This Guide
- Recommended Reading
- The Microchip Web Site
- Development Systems Customer Change Notification Service
- Customer Support
- Document Revision History

ABOUT THIS GUIDE

Document Layout

This document describes how to use the MCHPFSUSB Firmware for creating USB applications. The manual layout is as follows:

- **Chapter 1: Using the Microchip USB Firmware Framework** provides an overview of the framework, and how to use it in the design of new USB solutions.

Conventions Used in this Guide

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

Description	Represents	Examples
Arial font:		
Italic characters	Referenced books	<i>MPLAB[®] IDE User's Guide</i>
	Emphasized text	...is the <i>only</i> compiler...
Initial caps	A window	the Output window
	A dialog	the Settings dialog
	A menu selection	select Enable Programmer
Quotes	A field name in a window or dialog	"Save project before build"
Underlined, italic text with right angle bracket	A menu path	<u><i>File>Save</i></u>
Bold characters	A dialog button	Click OK
	A tab	Click the Power tab
'bnnnn	A binary number where <i>n</i> is a digit	'b00100, 'b10
Text in angle brackets < >	A key on the keyboard	Press <Enter>, <F1>
Courier New font:		
Plain Courier New	Sample source code	#define START
	Filenames	autoexec.bat
	File paths	c:\mcc18\h
	Keywords	_asm, _endasm, static
	Command-line options	-Opa+, -Opa-
	Bit values	0, 1
Italic Courier New	A variable argument	<i>file.o</i> , where <i>file</i> can be any valid filename
0xn timer	A hexadecimal number where <i>n</i> is a hexadecimal digit	0xFFFF, 0x007A
Square brackets []	Optional arguments	mcc18 [options] <i>file</i> [options]
Curly brackets and pipe character: { }	Choice of mutually exclusive arguments; an OR selection	errorlevel {0 1}
Ellipses...	Replaces repeated text	var_name [, var_name...]
	Represents code supplied by user	void main (void) { ... }

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RECOMMENDED READING

This user's guide describes how to use the MCHPFSUSB Firmware. Other useful documents are listed below. The following documents are available and recommended as supplemental reference resources.

MCHPFSUSB Firmware Release Notes

As new versions of the MCHPFSUSB Firmware are developed, they will be distributed along with release notes that may cover specific and key items not necessarily covered in this User's Guide. When new versions are released, they will be posted at the Microchip USB design center:

<http://www.microchip.com/usb/> (click on the "Full-Speed USB Solutions" link)

PICDEM FS USB Demonstration Board User's Guide (DS51526)

PIC18F87J50 FS USB Plug-In Module User's Guide (DS51678)

Official USB 2.0 Specifications

Chapter 9 in the official USB 2.0 specifications covers the commands that all USB peripheral devices must support. This chapter is especially important as it strongly influences the requirements of USB firmware. Chapters 5 and 8 also provide useful information regarding how data moves across the USB. The official USB specifications can be downloaded from the USB Implementers Forum web site:

<http://www.usb.org/>

THE MICROCHIP WEB SITE

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- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user's guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQ), technical support requests, online discussion groups, Microchip consultant program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

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The Development Systems product group categories are:

- **Compilers** – The latest information on Microchip C compilers and other language tools. These include the MPLAB C17, MPLAB C18 and MPLAB C30 C compilers; MPASM™ and MPLAB ASM30 assemblers; MPLINK™ and MPLAB LINK30 object linkers; and MPLIB™ and MPLAB LIB30 object librarians.
- **Emulators** – The latest information on Microchip in-circuit emulators. This includes the MPLAB ICE 2000 and MPLAB ICE 4000.
- **In-Circuit Debuggers** – The latest information on the Microchip in-circuit debugger, MPLAB ICD 2.
- **MPLAB IDE** – The latest information on Microchip MPLAB IDE, the Windows® Integrated Development Environment for development systems tools. This list is focused on the MPLAB IDE, MPLAB SIM and MPLAB SIM30 simulators, MPLAB IDE Project Manager and general editing and debugging features.
- **Programmers** – The latest information on Microchip programmers. These include the MPLAB PM3 and PRO MATE® II device programmers and the PICSTART® Plus development programmer.

CUSTOMER SUPPORT

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- Technical Support

Customers should contact their distributor, representative or field application engineer (FAE) for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document.

Technical support is available through the web site at: <http://support.microchip.com>

DOCUMENT REVISION HISTORY

Revision A (July 2007)

- Initial Release of this Document.

Chapter 1. Using the Microchip USB Firmware Framework

1.1 HIGHLIGHTS

The items discussed in this chapter are:

- Overview of the Framework
 - Configuring MPLAB® IDE for the Framework
 - Selecting the Microcontroller Configuration
- USB Firmware in the Framework

1.2 OVERVIEW OF THE FRAMEWORK

The Microchip USB Firmware Framework is a library that can be used to create new USB applications. It can be thought of as a reference design project, containing the necessary firmware code for USB operation and providing a placeholder for the user's code. The whole code project is contained within one single root project directory, with many subdirectories for source code organization.

The USB Framework is based on the latest versions (as this is written) of Microchip's development tools. To provide the best level of USB application support, you should verify that you have at least these revisions of the following tools before starting:

- MPLAB IDE, v 7.61
- Microchip C18 C Compiler, v 3.12

This section describes the importance in setting up the project paths and how the framework is organized.

1.2.1 The Framework Directory Structure

The file structure consists of a collection of subdirectories and specific files under a root project directory. The root directory for a USB project may be located in any location and have any valid directory name; however, the subdirectories' structure should always be maintained. Each of the example projects use this structure.

The following subdirectories and files should always be present:

Subdirectories:

- `_output`: Central location for output files
- `autofiles`: Contains USB global configuration file and descriptors
- `system`: Contains USB firmware
- `user`: Placeholder for the user's firmware

Files:

- `CleanUp.bat`: Delete all output files in this folder and any subdirectories.
- `io_cfg.h`: Maps pin names to pin functions; this file should be modified to match each target board. The default example is designed for the PICDEM FS USB demonstration board.
- `main.c`: The file which contains `main()` for the application.
- `MCHPUSB.mcp`: MPLAB IDE Project file.
- `MCHPUSB.mcw`: MPLAB IDE Workspace file.

1.2.2 The Framework Logical Structure

The USB Firmware Framework provides a set of modular firmware interfaces that handle most of the work for implementing USB communications. Figure 1-1 shows a typical USB program flow. Each firmware reference project is written to have a cooperative multitasking environment; thus, no blocking functions should be implemented.

The `main()` function is an infinite `while` loop that services different tasks. These can be logically thought of as either a USB task or a user task. USB tasks are handled by `USBDriverService()`, which polls and services all USB hardware interrupts. When a control endpoint transaction is received, `USBCtrlEPService()` is called. All transfers over the default control endpoints must follow the control transfer protocol as described in the USB specification.

The control transfer service is provided by functions in `usbctrltrf.c`. The first stage of all control transfers arrive as a request. A USB request can be either standard or class-specific. A standard request is serviced by the `USBCheckStdRequest()`, which handles the required requests as specified in Chapter 9 of the USB specification. A class-specific request must be handled by the firmware file that knows how to service it. Examples of device classes are Human Interface Device (HID) and Communication Device Class (CDC). (The example in Figure 1-1 shows HID; it could refer to any other device class just as easily.) The handlers for a class-specific request should be contained in the specific device class firmware file, such as `hid.c` or `cdc.c`. The naming scheme for a function that services a class-specific request is `USBCheck<class name>Request()`, where `<class name>` can be any class-specific names.

The USB enumeration process is handled mainly in `usb9.c`. One of the most important steps in the enumeration process is the handling of a `SET_CONFIGURATION` request, which is done by `USBStdSetCfgHandler()`. This function can be modified by the user to call the appropriate functions to initialize the application endpoints. Each specific device class firmware should have one endpoint initialization routine. The naming convention for this function is `<class name>InitEP()`, where `<class name>` can be any device class names. An example is `HIDInitEP()`, which contains example code on how to initialize a group of endpoints that are used in the class. Users should take care to check which configuration index is being asked to be set by the USB host. A device can have multiple configurations, and not all interfaces may be the same across different configurations.

The user's application code is also called from the main program loop; it resides under the default function name, `ProcessIO()`. When the application needs to send or receive a data packet, it can call a prewritten function that services the transmit or receive functionality which is declared in the class-specific firmware code, such as `HIDRxReport()` and `HIDTxReport()`.

USB device configuration is also handled in a modular manner by modifying variables in a small number of files; the information is then made globally available at compile time. The files are tightly interdependent and pass information between themselves during compile time to create the complete USB configuration. The relationships are shown in Figure 1-2. Customizing the configuration files is discussed in **Section 1.3 "USB Firmware in the Framework"**.

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FIGURE 1-1: RELATIONSHIPS BETWEEN MICROCHIP USB FRAMEWORK FILES AND A TYPICAL HID APPLICATION

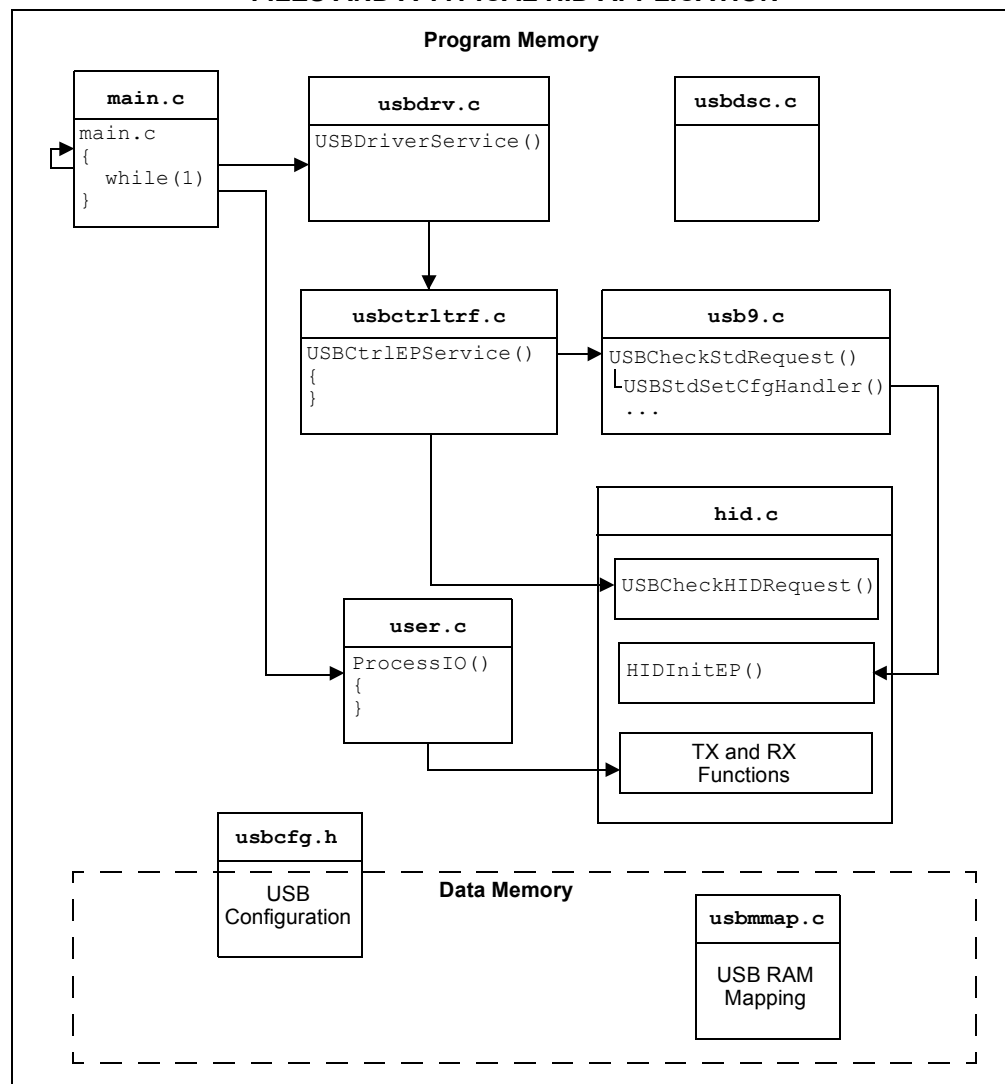
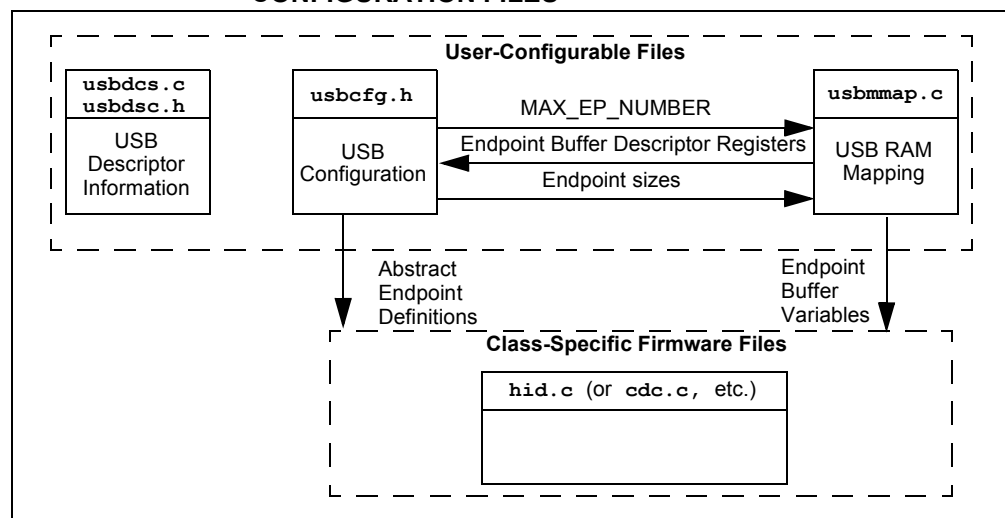


FIGURE 1-2: COMPILE-TIME RELATIONSHIPS BETWEEN USB CONFIGURATION FILES



1.2.3 Configuring MPLAB IDE for the USB Framework

When setting up a project from the reference design, the first thing to check is the project paths. These should be updated to reflect the actual project's root directory as needed. The steps in updating the project paths will be demonstrated through an example.

In this example, we will use the HID Mouse Reference project, located in the directory, `C:\MCHPFSUSB\fw\HID\Mouse`. You may need to adjust your target directories according to where the project is actually located during installation.

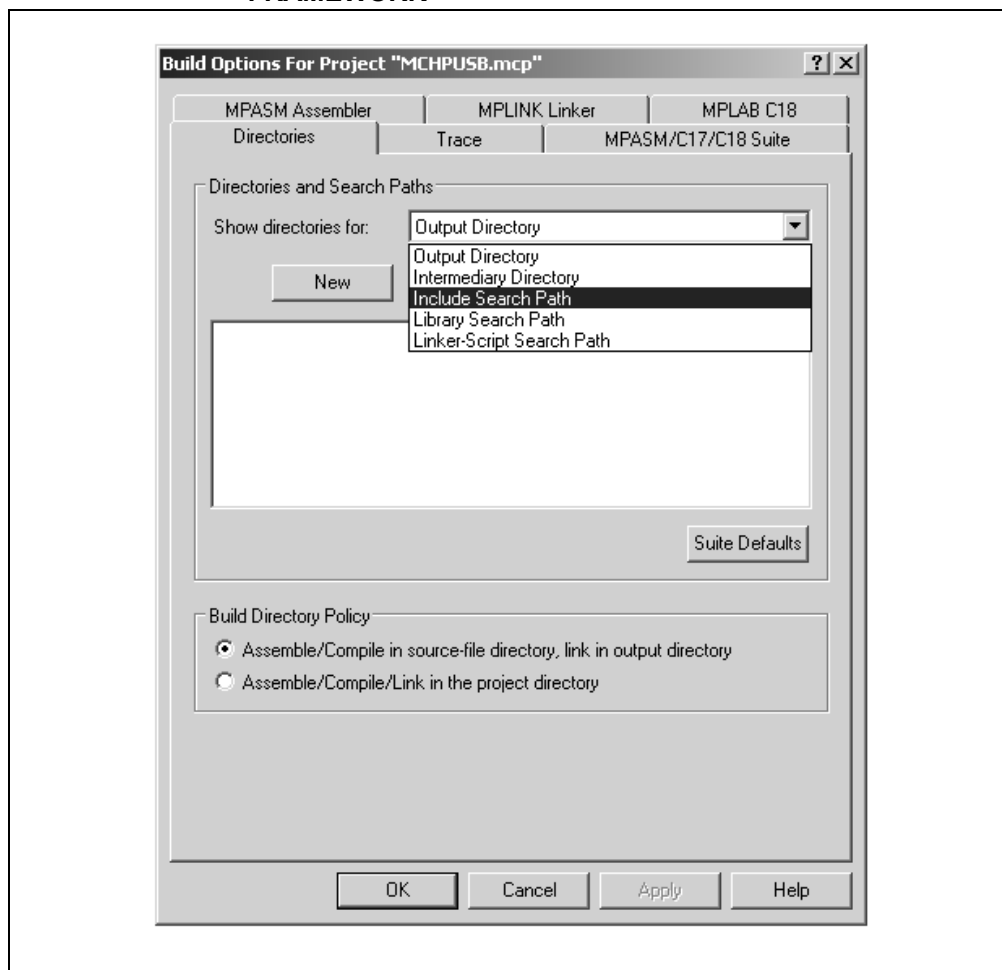
To open a project workspace:

1. Launch MPLAB IDE.
2. From the MPLAB IDE menu bar, select File > Open Workspace...
3. Navigate and select the project or workspace file,
`C:\MCHPFSUSB\fw\HID\Mouse\MCHPUSB.mcw` (or `MCHPUSB.mcp`).
4. Return to the menu bar and select Project > Build Options... > Project. The Build Options dialog appears (Figure 1-3).
5. Click on the **Directories** tab and verify the following:
 - The "Output Directory" and "Intermediates Directory" paths should point to the `_output` folder under your root project directory.
 - The "Include Path" directory should point to the project's root directory.
 - The "Library Path" should point to the "lib" directory under the C18 program folder.
 - The "Linker-Script Path" should point to the directory of the project's linker script file.

Note 1: In some cases, the C18 compiler may fail to compile correctly, giving an error that certain header files from the `mcc18` library could not be found. In this case, add the path `C:\mcc18\h` after the project root path in the "Include Path" field.

2: If the C18 compiler is installed in a path other than `C:\mcc18\`, the actual path should be used instead.

FIGURE 1-3: CONFIGURING MPLAB® IDE FOR THE MICROCHIP USB FRAMEWORK



1.2.4 Selecting the Hardware Configuration

Microchip's current PIC18 USB microcontroller families share the same basic set of USB registers and names. As a result, the MCHPFSUSB Framework can be ported to work with the different PIC18 USB microcontroller families with little to no modification.

The MCHPFSUSB Framework is currently distributed as several separate projects which all share the same basic USB "Chapter 9" firmware needed for device enumeration. These individual projects differ in that they each include additional code to demonstrate implementation examples for specific USB device classes. For example, a Human Interface Device (HID) class USB device must support additional commands specific to the HID class specifications, in addition to the Chapter 9 commands that all USB devices must support.

By default, these projects are configured to work with the PICDEM FS USB Demo Board (microchipDIRECT part number: DM163025), which features the PIC18F4550 USB microcontroller.

Using the Microchip USB Firmware Framework

To use these projects with other PIC18 USB microcontrollers or circuit board platforms, the following changes will be needed:

1. Open the MPLAB IDE project.
2. Select the microcontroller which will be used:
Menu bar --> Configure --> Select Device.
3. Replace the linker script in the project with the appropriate device-specific linker script. These can be found in the `\lkr` directory inside the default installation directory for the C18 compiler.
4. Edit the `usbcfg.h` file by uncommenting the `#define` statement for the demo board which will be used (and comment the other choices). See highlighted section in Figure 1-4. This step may differ between the different projects, so refer to the MCHPFSUSB release notes which are distributed with the firmware for more details about this step.

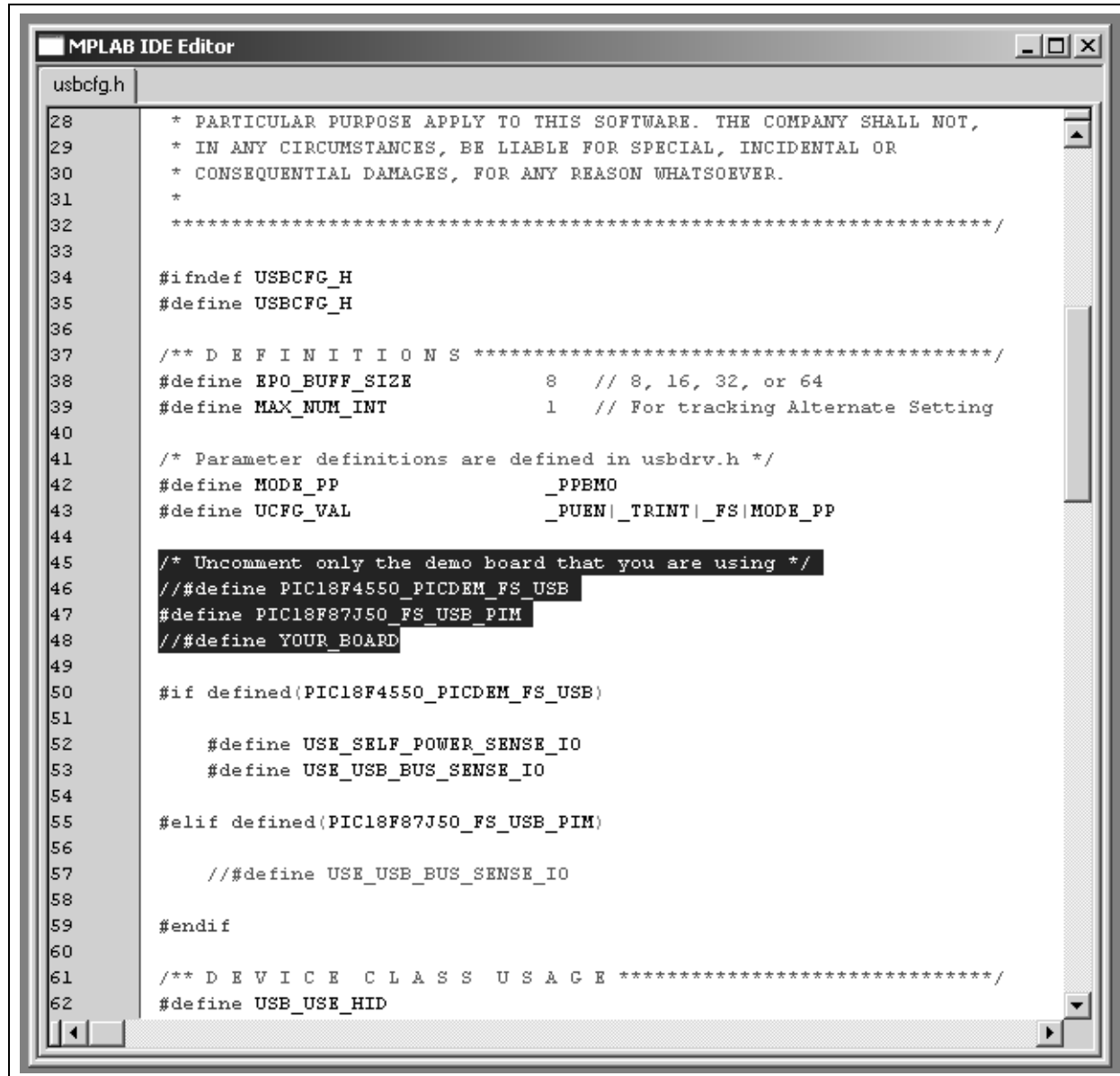
Although the USB-specific registers are the same between the PIC18F4550 family and other PIC18 USB microcontrollers, such as the PIC18F87J50 family, a few differences still exist. For example, when configured for a PLL-based oscillator mode, the PIC18F4550 will power-up by default with the PLL enabled. On the PIC18F87J50 family of devices, the PLL is initially disabled even when configured for a PLL-based oscillator mode. User firmware must set the `OSCTUNE<PLEN>` bit at least two milliseconds before enabling the USB module (if the USB module clock is being derived from the PLL).

To accommodate these types of differences, the source code for the MCHPFSUSB Framework uses `#if defined(//demo board name)` statements. By uncommenting the `#define` statement of step 4, the C18 compiler will be able to know which `#if defined(//demo board name)` statements are applicable for the demo platform/device being used.

If developing for a non-Microchip demo board platform, additional changes may also be needed. The example framework projects make use of the hardware features available on the demo boards, such as LEDs, push buttons, temperature sensor, RS-232 connector, etc. When developing for a different platform, these aspects of the projects will either need to be replaced or removed. The `io_cfg.h` file maps functions to pin names and will likely need modification.

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FIGURE 1-4: SELECTING THE HARDWARE PLATFORM



Using the Microchip USB Firmware Framework

1.3 USB FIRMWARE IN THE FRAMEWORK

The subdirectories' `autofiles` and `system` contain the USB firmware source code in the framework. Some of these files should never be modified, while others must be edited to configure the application. Each folder and its files will be discussed in details of what they do and how to modify them to match your application.

1.3.1 Autofiles Directory

This directory contains three key configuration files for USB operation:

- `usbcfg.h`: Global USB Configuration File
- `usbdsc.c`: USB Descriptor File
- `usbdsc.h`: USB Descriptor File Header

1.3.1.1 `usbcfg.h`

This header file is the most important file of the entire project. It defines the endpoints mapping to their class functions. It also defines the Microchip USB ID (MUID) number, which is used to determine which USB class currently owns the control transfer in progress. Finally, it defines the maximum buffer size for endpoint 0.

To centralize the configuration of important USB features, all of the USB-related compile-time options are found here. The file is constructed as a series of `#define` compiler directives. The options to configure are:

- `EP0_BUFF_SIZE` [*buffer_size*]
- `MAX_NUM_INT` [*max*]
- `MODE_PP` [*_PPBMn*]
- `UCFG_VAL` [*option1* | *option2...*]
- `USE_SELF_POWER_SENSE_IO`
- `USE_USB_BUS_SENSE_IO`
- `USB_USE_GEN` or `USB_USE_CDC` or `USB_USE_HID`
- `MAX_EP_NUMBER` [*max_ep*]

EP0_BUFF_SIZE defines the buffer size for endpoint 0. It can have a valid value of 8, 16, 32 or 64 bytes. This definition is used globally in the project for many things. It is used during project build to allocate appropriate buffer size for endpoint 0. It is used in the USB descriptor to notify the USB host of the size of the endpoint 0 buffer. It is also used during control transfer operation.

When defining this variable, note that a low-speed USB device can only use an 8-byte buffer, while a full-speed USB device can use an 8, 16, 32 or 64-byte buffer.

MAX_NUM_INT defines the size of the array which keeps track of the active alternate setting for each interface, which can be switched during operation. Valid values are integers [0, 1, 2,...]. If a device has multiple configurations, the number of interfaces from the configuration with the highest number of interfaces should be used.

For example, a device with two configurations has three interfaces in the first configuration and two interfaces in the second. In this case, `MAX_NUM_INT` should be three.

MODE_PP defines the Ping-Pong Buffer mode to be used during run time. The function of each mode is explained in the USB chapter of the device data sheet.

Note: The current version of the firmware only supports <code>_PPBM0</code> mode.
--

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UCFG_VAL defines the initial value for the UCFG Special Function Register. The allowed values are:

- **_LS** or **_FS**: Select Low or Full-Speed mode
- **_TRINT** or **_TREXT**: Select Internal or External Transceiver mode
- **_PUEN**: Use internal USB pull-up resistor
- **_OEMON**: Use SIE output indicator
- **_UTEYE**: Enable eye pattern test output

The options can be ORed together (for example, `#define UCFG_VAL _PUEN|_TRINT|_FS`). This value is used by the firmware framework to initialize the UCFG register. A full explanation of the options can be found in the description of the UCFG register in the USB chapter of the device data sheet.

- | |
|--|
| <p>Note 1: If the _LS option is selected, the device clock configuration must be changed to support low-speed operation, Refer to the device data sheet for additional information.</p> <p>2: The _UTEYE option is used only for device testing and never in live applications. When _UTEYE is enabled, the device transmits continuously. Do not plug the device to a USB host when the option is enabled.</p> <p>3: Not all PIC18 USB microcontrollers support all of the listed settings. Refer to the USB chapter in the device-specific data sheet to determine which modes are valid for a given device.</p> |
|--|

USE_SELF_POWER_SENSE_IO indicates that the microcontroller is sensing the presence of on-board power through an I/O pin. If the target board design does not use an I/O pin to detect the presence of self-power, this definition must be commented out.

USE_USB_BUS_SENSE_IO indicates that the firmware will use the pin defined in `io_cfg.h` to determine when to enable the USB module. If the target board design does not use an I/O pin to detect the presence of the USB bus, this definition must be commented out.

When **USE_USB_BUS_SENSE_IO** is undefined, the USB module will always be enabled. Using this feature helps to improve the power efficiency of the system because the USB module is only enabled when the bus is present. Additionally, in order for the device to pass USB compliance certification, all self-powered devices are required to support a bus sense feature. Self-powered devices which do not implement this feature will fail the back drive voltage tests. The USB specifications require that devices should not source current on D+ or D- (and never VBUS) unless the host is actively powering the VBUS line. A self-powered device will not know when the host is actively powering VBUS (and when it is acceptable to enable the D+ or D- pull-up resistor) unless a bus sense feature is implemented. Purely bus-powered devices do not need to implement this feature, and this feature may be commented out.

USB_USE_GEN, **USB_USE_CDC** and **USB_USE_HID** are used to indicate which USB classes should be included in the code project. When each of these are defined, it tells the USB global header file, `usb.h`, which class-specific header files to include. The `usb.h` header is used globally as the necessary include file when using the USB library. If the HID class is used, then `hid.c` and `hid.h` should also be added to the MPLAB IDE project. If the CDC class is used, then `cdc.c` and `cdc.h` should also be added to the MPLAB IDE project.

This definition is also used when the SET_CONFIGURATION request is received. Users can modify the 'Modifiable Section' in the `USBStdSetCfgHandler` function in `usb9.c`. The calls located in the modifiable section initialize endpoints used by each specific USB class, which are mapped by `usbcfg.h`.

Using the Microchip USB Firmware Framework

MAX_EP_NUMBER must equal the highest endpoint number used in the project. For example, if the highest endpoint number used is endpoint 5, then **MAX_EP_NUMBER** should equal five. This definition is used mainly in the `usbmmmap.c` to allocate the buffer descriptor registers.

1.3.1.2 `usbdsc.c` AND `usbdsc.h`

These files contain the USB descriptor information for the device. The main file, `usbdsc.c`, defines the descriptor itself; `usbdsc.h` defines the descriptor structure, which is used to calculate the descriptor size with the `sizeof()` statement. When a descriptor is added or removed from the main configuration descriptor (i.e., CFG01), the user must also change the descriptor structure defined in `usbdsc.h`.

A typical configuration descriptor consists of these components:

- At least one configuration descriptor (USB_CFG_DSC)
- One or more interface descriptors (USB_INTF_DSC)
- One or more endpoint descriptors (USB_EP_DSC)

In addition, there is usually a descriptor string that provides a plain text description of the device.

1.3.1.2.1 Customizing `usbdsc.c`

The version of `usbdsc.c` included with the Framework Firmware indicates which parameters must be defined, and can serve as a template for developing new device descriptors. Most items should be self-explanatory, but some options are not explained in the file's comments and are expanded upon below.

• **USB_CFG_DSC**

The configuration attribute (the item immediately following the string index) must always have the `_DEFAULT` definition at the minimum. Two additional options, `_SELF` and `_RWU`, can be ORed with `_DEFAULT`. `_SELF` tells the USB host that this device is self-powered, while `_RWU` tells the USB host that the device supports remote wake-up. Definitions for these options are provided in `usbdefs_std_dsc.h`.

• **USB_EP_DSC**

An endpoint descriptor has a form similar to:

```
sizeof(USB_EP_DSC), DSC_EP, _EP01_OUT, _BULK, 64, 0x00
```

The first two parameters specify the length of this endpoint descriptor (7) and the descriptor type. The next parameter identifies the endpoint. It takes the format:

```
_EP<##>_<dir>
```

where `##` is the endpoint number and `dir` is the direction of transfer. The `dir` has the value of either 'OUT' or 'IN'.

The definitions are provided in:

```
usbdefs_std_dsc.h.
```

The next parameter identifies the type of the endpoint. Available options are `_BULK`, `_INT`, `_ISO` and `_CTRL` (for Bulk, Interrupt, Isochronous and Control endpoints, respectively). The `_CTRL` is not typically used because the default control transfer endpoint is not defined in the USB descriptors. When `_ISO` is used, additional options can be ORed with it. For example:

```
_ISO | _AD | _FE
```

describes the endpoint as an isochronous pipe with adaptive and feedback attributes. See `usbdefs_std_dsc.h` and the USB specification for details.

The final parameters define the maximum size of the endpoint and the polling interval.

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- **The USB Descriptor String**

Rather than appearing as a simple string of text, the descriptor is formatted in a particular data structure. The string descriptor array takes the format:

```
rom struct{byte bLength;byte bDscType;word string[size];}sdxxx={
sizeof(sdxxx),DSC_STR,<text>;
```

This structure provides a means for the C compiler to calculate the length of string descriptor, `sdxxx`, where `xxx` is the string index number. The first two bytes of the descriptor are the descriptor length and type.

The remaining `<text>` are string texts which must be in Unicode format. This is achieved by declaring each character as a word type. The whole text string is declared as a word array with the number of characters equal to `<size>`; which must be calculated manually by counting characters and then entered into the array declaration. For example, if the string is "USB", then the string descriptor should be (using index 02):

```
rom struct{byte bLength;byte bDscType;word string[3];}sd002={
sizeof(sd002),DSC_STR,'U','S','B'};
```

A USB project may have multiple strings. The firmware supports the management of multiple strings through a look-up table, which is defined as:

```
rom const unsigned char *rom USB_SD_Ptr[]={&sd000,&sd001,&sd002};
```

The above example has 3 strings (`sd000`, `sd001` and `sd002`). Strings can be removed or added as needed. The strings are managed by the look-up table `USB_SD_Ptr`; the index of the string must match the index position of the array, (`&sd000` must be in position `USB_SD_Ptr[0]`, and so on). The look-up table `USB_SD_Ptr` is used by the `USBStdGetDscHandler` function in `usb9.c`.

`sd000` is a specialized string descriptor. It defines the language code, which is usually US English (0x0409).

1.3.1.2.2 Customizing `usbdcs.h`

In the header file, `usbdsc.h`, variables for each of the descriptor components are named with the following conventions:

USB_CFG_DSC types are named `cdxx`, where `xx` is the configuration number. This number should match the actual index value of the configuration.

USB_INTF_DSC types are named `i<yy>a<zz>`, where `yy` is the interface number and `zz` is the alternate interface number.

USB_EP_DSC types are named `ep<##><d>i<yy>a<zz>`, where `##` is the endpoint number and `d` is the direction of transfer. The interface name should also be listed as a suffix to identify which interface the endpoint belongs to.

Example 1-1 shows the structure in `usbdsc.h` of a configuration descriptor. This device has one configuration with two interfaces: interface 0 with two endpoints (in and out), and interface 1 with one endpoint (in). The hierarchy of the descriptors shown here follows the USB specification requirement. All endpoints belonging to an interface should be listed immediately after that interface.

EXAMPLE 1-1: DEFINING A CONFIGURATION IN USBDSC.H

```
#define CFG01 rom struct                                \
{  USB_CFG_DSC    cd01;                                \
   USB_INTF_DSC   i00a00;                              \
   USB_EP_DSC     ep01o_i00a00;                        \
   USB_EP_DSC     ep01i_i00a00;                        \
   USB_INTF_DSC   i01a00;                              \
   USB_EP_DSC     ep02i_i01a00;                        \
} cfg01
```

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1.3.1.2.3 Adding Configurations

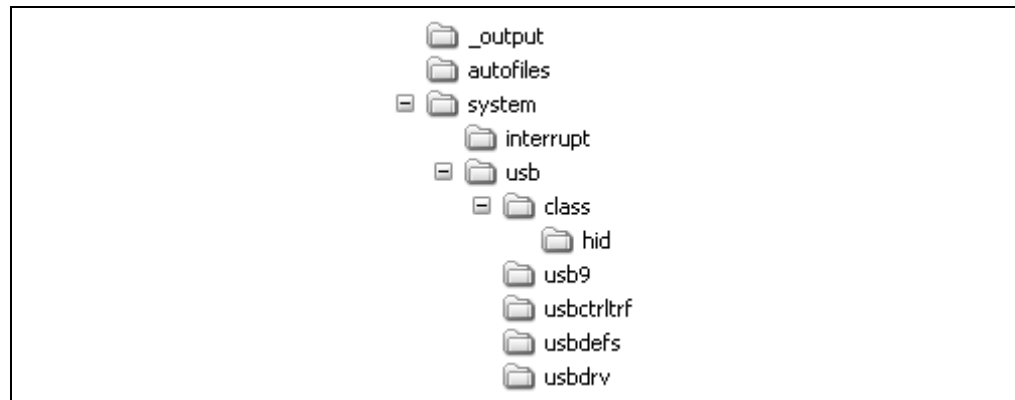
A USB device may have more than one configuration descriptor (e.g., CFG02, CFG03, etc.). To add another configuration descriptor, implement a new set of structures, similar to CFG01, to both `usbdsc.c` and `usbdsc.h`. These will be named CFG02 (or CFG03, and so on). Once this is done, add the new configuration descriptor name (`cfg02`, `cfg03`) to the look-up table `USB_CD_Ptr`, in the same method used for managing descriptor strings. `USB_CD_Ptr[0]` is a dummy place holder for configuration 0, the unconfigured state defined by the USB specification.

The configuration handler, `USBStdSetCfgHandler`, must also be modified to support the additional configurations.

1.3.2 System Directory

The project system directory contains many of the USB core function files. Its structure is shown in Figure 1-5.

FIGURE 1-5: DIRECTORY TREE STRUCTURE FOR THE USB FRAMEWORK



In addition to the USB memory manager, `usbmmap.c`, the key files discussed in this section are located in the following folders in the USB folder:

- `usb9`: `usb9.c` and `usb9.h`
- `usbctrltrf`: `usbctrltrf.c` and `usbctrltrf.h`
- `usbdrv`: `usbdrv.c` and `usbdrv.h`
- `usbdefs`: the standard definition files `usbdefs_ep0_buff.h` and `usbdefs_std_dsc.h`.

1.3.2.1 `usbmmap.c`

This file is the USB memory manager. It serves as a compile-time memory allocator for the USB endpoints. It uses the compile-time options passed from `usbcfg.h` to instantiate endpoints and endpoint buffers.

Endpoints are defined using the endpoint number and the direction of transfer. For simplicity, `usbmmap.c` only uses the endpoint number in the BDT register allocation scheme. This means if `usbcfg.h` states that the `MAX_EP_NUMBER` is number 1, then four BDTs will be instantiated: one each for endpoint 0 in and endpoint 0 out, which must always be instantiated for control transfer by default, and one of each set for endpoint 1 in and endpoint 1 out. The naming convention for instantiating a BDT is:

`ep<#>B<d>`

where `#` is the endpoint number, and `d` is the direction of transfer, which could be either:

`<i>` or `<o>`.

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The USB memory manager uses `MAX_EP_NUMBER`, as defined in `usbcfg.h`, to define the endpoints to be instantiated. This represents the highest endpoint number to be allocated, not how many endpoints are used. Since the BDTs for endpoints have hardware-assigned addresses in Bank 4, setting this value too high may lead to inefficient use of data RAM. For example, if an application uses only endpoints EP0 and EP4, then the `MAX_EP_NUMBER` is 4 and not 2. The in-between endpoint BDTs in this example (EP1, EP2 and EP3) go unused, and the 24 bytes of memory associated with them are wasted. (This assumes Ping-Pong Buffer mode 0, which assigns 4 bytes to each BDT, and one BDT to the in and out endpoints for each endpoint.) It does not make much sense to skip endpoints, but the final decision lies with the user.

The instantiated endpoint name is then used in `usbcfg.h` for mapping the endpoint to its function. For example, assume a USB device class “FOO”, which uses one in and one out endpoint, each one being 64 bytes. In Example 1-2, we have chosen this class to use endpoint 1. (The names are arbitrary and can be anything other than `FOO_??????`). For abstraction, any code written for devices of this class should use the abstract definitions such as `FOO_BD_OUT`, `FOO_BD_IN` and so on, and not `ep1Bo` or `ep1Bi`. Note that the endpoint size defined in `usbcfg.h` is again used in `usbmmap.c`. This shows that the relationship between the two files is tightly related.

EXAMPLE 1-2: DEFINING THE ENDPOINTS FOR CLASS FOO

```
#define FOO_INTF_ID      0x00
#define FOO_UEP          UEP1
#define FOO_BD_OUT       ep1Bo
#define FOO_BD_IN        ep1Bi
#define FOO_EP_SIZE      64
```

The endpoint buffer for each USB function must be located in a dual port or dual access RAM area (e.g., 0x400 to 0x7FF on the PIC18F4550, or 0x000 to 0xF3F on the PIC18F87J50), but should not overlap with the buffer descriptor table. An example declaration is:

```
volatile far unsigned char[FOO_EP_SIZE] data;
```

The `volatile` keyword tells the compiler not to perform any code optimization on this variable because its content could be modified by the hardware. The `far` keyword tells the compiler that this variable is not located in the Access RAM area (0x000 to 0x05F).

For the variable to be globally accessible by other files, its prototype should also be listed in the header file, `usbmmap.h`, with an `extern` keyword, such as:

```
extern volatile far unsigned char[FOO_EP_SIZE] data;
```

1.3.2.2 `usbdrv.c`

This file provides low-level USB services, and handles all USB hardware interrupts. This section describes functions which are relevant to user in details.

1.3.2.2.1 `USBCheckBusStatus` Function

This function should be called once per main loop. When an I/O sense pin is used to detect the attachment and detachment of a USB cable, this routine enables or disables the USB module accordingly. This helps increase the power efficiency of the system and is required in order for self-powered devices to pass USB compliance certification. If an I/O sense pin is not used, the `#define USE_USB_BUS_SENSE_IO` statement in `usbcfg.h` should be commented out. This causes `USBCheckBusStatus()` to enable the USB module after device Reset regardless of the attachment of a USB cable.

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1.3.2.2.2 USBDriverService Function

This function polls all of the USB hardware interrupt flags in the UIR and UIE registers to check if a USB event has occurred, and services the event. It also clears the USB transaction complete flag, TRNIF, which is set after each USB transaction successfully completes.

Issues can occur when an application tries to send or receive transactions more than four times without clearing the TRNIF flag. This is because the 4-level hardware FIFO stack for storing transaction completions can only be emptied one level at a time by clearing TRNIF. When more than four transactions are received without TRNIF being cleared, no more transactions can be processed. An example of how this may happen is shown in Example 1-4. This stops the USB module from responding to any further host requests until more stack becomes available. More information regarding USTAT and transaction FIFO can be found in the USB chapter of the of the microcontroller device data sheet.

The user's application code should not clear the TRNIF bit directly, but call `USBDriverService()` instead, as in Example 1-3 and Example 1-5. Clearing the TRNIF bit directly if an endpoint 0 transaction occurs first will cause that transaction to be lost and not be serviced by the library firmware.

EXAMPLE 1-3: TYPICAL METHOD OF PERFORMING ONE TRANSACTION PER LOOP (PSEUDO CODE)

```
main()
{
    while(1)
    {
        USBDriverService();

        if(!mHIDTxIsBusy())
            HIDTxReport();
    } //end while
} //end main
```

EXAMPLE 1-4: INCORRECT METHOD OF PERFORMING MULTIPLE TRANSACTIONS PER LOOP (PSEUDO CODE)

```
main()
{
    while(1)
    {
        USBDriverService();

        while(mHIDTxIsBusy());
        HIDTxReport();           // 1st Tx
        while(mHIDTxIsBusy());
        HIDTxReport();           // 2nd Tx
        while(mHIDTxIsBusy());
        HIDTxReport();           // 3rd Tx
        while(mHIDTxIsBusy());
        HIDTxReport();           // 4th Tx
        while(mHIDTxIsBusy());   // This will never turn false
                                // because the USTAT FIFO is full
        HIDTxReport();           // 5th Tx - Unreachable code

    } //end while
} //end main
```

EXAMPLE 1-5: CORRECT METHOD OF PERFORMING MULTIPLE TRANSACTIONS PER LOOP (PSEUDO CODE)

```
main()
{
    while(1)
    {
        USBDriverService();

        while(mHIDTxIsBusy());
        HIDTxReport();           // 1st Tx
        USBDriverService();
        while(mHIDTxIsBusy());
        HIDTxReport();           // 2nd Tx
        USBDriverService();
        while(mHIDTxIsBusy());
        HIDTxReport();           // 3rd Tx
        USBDriverService();
        while(mHIDTxIsBusy());
        HIDTxReport();           // 4th Tx
        USBDriverService();
        while(mHIDTxIsBusy());
        HIDTxReport();           // 5th Tx
        USBDriverService();

        //other application code
    } //end while
} //end main
```

1.3.2.2.3 USBSuspend Function

This routine first puts the USB module into Suspended mode and enables the USB bus activity interrupt. Additionally, there is a user-modifiable section for implementing power-saving schemes. In order to pass USB compliance testing, devices must consume no more than 500 μ A or 2.5 mA (depends on configuration, see official USB specifications) from VBUS when the device is in the USB suspend state. This user-modifiable section would be where clock switching, executing the `SLEEP` instruction or other forms of power management should be implemented. Options for implementing power-saving are discussed in Microchip application note AN950, "Power Management for PIC18 USB Microcontrollers with nanoWatt Technology" (DS00950).

Before putting a device to Sleep, a wake-up source must be enabled first. For the USB bus activity interrupt to be a wake-up source, set the `ACTVIE` bit in the `UIE` register. Note that the main USB interrupt in the `PIE2` register must also be enabled, as shown in Example 1-6.

EXAMPLE 1-6: ENABLING USB SUSPEND

```
PIR2bits.USBIF = 0;    // Make sure flag is cleared
PIE2bits.USBIE = 1;    // Set USB wakeup source
Sleep();               // Goto sleep
PIR2bits.USBIF = 0;    // Clear flag
PIE2bits.USBIE = 0;    // Disable USB interrupt
```

1.3.2.2.4 USBWakeFromSuspend Function

The routine is called when a bus activity interrupt is set. It disables the bus activity interrupt and re-enables the USB module.

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1.3.2.2.5 USBRemoteWakeup Function

When the host PC is in a low-power state (such as suspend to RAM), it will normally continue to supply some power on the **V_{BUS}** supply pin, and will monitor the D+ and D- data lines for a remote wake-up signal. USB peripheral devices may implement a remote wake-up capability, where they can send special signalling to the host indicating it should wake-up and resume full power operation. An example application where this feature would typically be used would be a USB infrared remote control receiver. If the user presses the “power” button on the remote control, the USB infrared receiver could detect/decode this signal, and then send special signalling to the host PC to wake it up.

A device may send the special remote wake-up signalling to the host PC by calling the `USBRemoteWakeup()` function. Example 1-7 shows sample code that would reside in the `USBSuspend()` function which would enable both the USB and external stimulus wake-up sources, and call the `USBRemoteWakeup()` function if the wake-up source is not USB. In this example, either USB traffic or the `PORTB` interrupt-on-change feature would be used to wake-up the microcontroller. If the microcontroller wake-up source happened to be a change in the `PORTB` value (perhaps due to a user pressing a push button on one of the `PORTB` pins), the `USBRemoteWakeup()` function is called and would attempt to wake-up the host PC.

EXAMPLE 1-7: ENABLING USB REMOTE WAKE-UP

```
PIR2bits.USBIF = 0;           // Make sure flag is cleared
INTCONbits.RBIF = 0;          // Make sure flag is cleared
PIE2bits.USBIE = 1;           // Set USB wakeup source
INTCONbits.RBIE = 1;          // Set port change wakeup source

Sleep();                      // Goto sleep

if(INTCONbits.RBIF == 1)      // Check if the wakeup source
                             // is the port change interrupt
{
    USBRemoteWakeup();        // If yes, attempt Remote Wakeup
}                             // end if

PIR2bits.USBIF = 0;           // Clear flag
PIE2bits.USBIE = 0;           // Disable USB interrupt
INTCONbits.RBIF = 0;          // Clear flag
INTCONbits.RBIE = 0;          // Disable port change interrupt
```

1.3.2.3 usbctrltrf.c

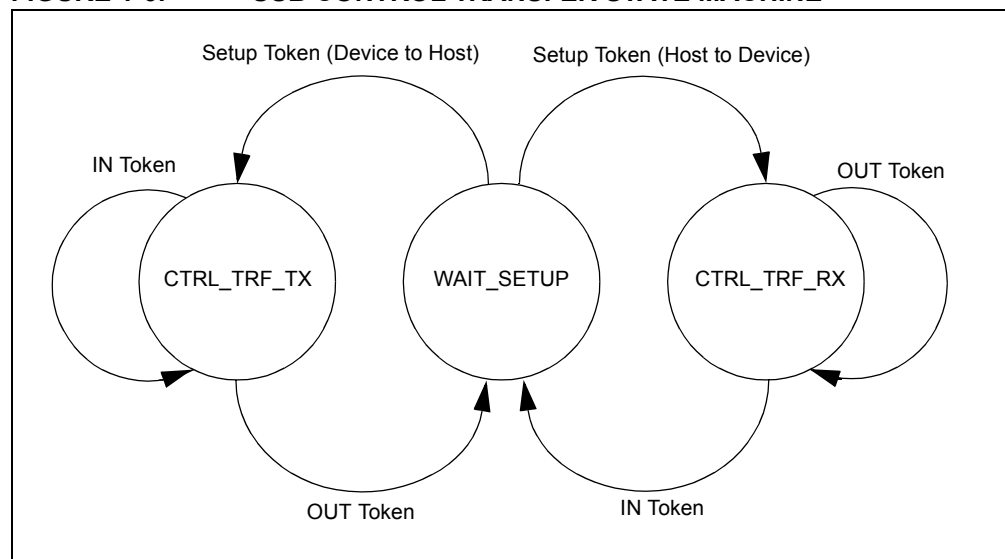
This file manages the control transfer, and provides services to all USB classes that need to handle USB requests (USB Chapter 9, HID, CDC, etc.). Since the control transfer service is shared among many USB classes and most transfers expand over multiple transactions, it is important to keep track of which class owns the current control transfer session. This is done by the use of Microchip USB ID (MUID). When MUID is equal to `MUID_NULL`, it means no classes are capable of handling the request. If the handler in `usb9.c` knows how to service a request, the current control transfer session variable is updated to equal `MUID_USB9`. Similarly if a HID request is received, then the MUID would be `MUID_HID`.

The definitions for MUID are defined in `usbcfg.h` and are only project-specific. This means two different projects could have different sets of MUIDs. It is up to the user to manage the usage and assignment of MUID in each project in `usbcfg.h`.

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Each control transfer has three stages: Setup, Data and Status. The state machine for handling different control transfer stages in Microchip USB firmware is illustrated in Figure 1-6. There are three different states: WAIT_SETUP, CTRL_TRF_TX and CTRL_TRF_RX.

FIGURE 1-6: USB CONTROL TRANSFER STATE MACHINE



`USBCtrlEPService()` is called from `usbdrv.c`. It only services transactions that come through endpoint 0. It checks for a different transaction type to call appropriate handlers (Endpoint 0 SETUP, Endpoint 0 OUT or Endpoint 0 IN).

If the transfer stage is SETUP, then `USBCtrlTrfSetupHandler()` is called to service the setup packet. Each USB control transfer setup packet is always 8 bytes long. There are three steps in servicing a setup packet:

1. The routine initializes the control transfer state machine.
2. It then calls on each of the class-specific request handlers in an attempt to find out if any handlers know how to service the request.
3. Once all request handlers have had a chance to analyze the setup packet, the function, `USBCtrlEPServiceComplete()`, checks the transfer direction of the data stage to determine how to prepare endpoint 0.

`USBCtrlEPServiceComplete()` wraps the remaining tasks in servicing a setup packet. Its main task is to set the endpoint controls appropriately for a given situation. There are three possible outcomes:

- Endpoint 0 is stalled if the request cannot be serviced.
- Endpoint 0 is set up for transferring data to the host during the data stage.
- Endpoint 0 is set up for receiving data from the host during the data stage.

The data stage can be expanded over multiple USB transactions. For example, a USB string descriptor is allowed to be much larger than 8 bytes long. If the endpoint buffer has been configured for 8 bytes maximum, the entire string descriptor cannot be sent to the host in a single transaction. Instead, it must be split up into multiple transactions of up to 8 bytes each.

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In order to handle this scenario, it is important to keep track of the data source, data destination, data count and data type. These are tracked and updated using four dedicated variables:

- `pSrc`
- `pDst`
- `wCount`
- the memory type flag bit, `usb_stat.ctrl_trf_mem`, which can have the value of `_ROM` or `_RAM`

When writing a request handler to send control transfer data from a peripheral device to a host, make sure to do the following:

1. Set data source:
 - For a RAM location: `pSrc.bRam = <RAM buffer location>;`
 - For a ROM location: `pSrc.bRom = <program memory location>;`
2. Set memory source type:
`usb_stat.ctrl_trf_mem = <_ROM or _RAM>;`
3. Set the size of data to transfer:
`wCount._word = <size of data to transfer>;`
4. The data destination (IN endpoint buffer) address is handled automatically by `usbctrltrf.c`; the destination is the `CtrlTrfData` buffer space defined in `usbmmmap.c`

When writing a request handler to receive control transfer data from a host over multiple transactions, make sure to do the following:

1. Set data destination:
`pDst.bRam = <RAM buffer location>` (Note that the memory destination type has to always be `_RAM`)
2. Initialize the receive counter, `wCount._word`, to zero
3. The data 'source' (OUT endpoint buffer) address is handled automatically by `usbctrltrf.c`; the 'source' is the `CtrlTrfData` buffer space defined in `usbmmmap.c`

Once the status stage is complete, the control transfer session owner (determined by the MUID value) can process the received data. The data destination is defined in the setup stage, and the length of received data is stored in `wCount._word`.

1.3.2.4 `usb9.c`

This file handles standard USB requests as defined in Chapter 9 of the USB specification, and handles the enumeration process. The function of interest in this file is `USBStdSetCfgHandler()`, which users must modify to match the application's configuration setup and behavior.

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Fax: 82-53-744-4302

Korea - Seoul

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Fax: 82-2-558-5932 or
82-2-558-5934

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