TB054

An Introduction to USB Descriptors

With a Gameport to USB Gamepad Translator Example

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INTRODUCTION

This Technical Brief demonstrates the translation of a gameport gamepad to a USB gamepad using the PIC16C765, Microchip's low speed USB PICmicro® MCU. The purpose of this Technical Brief is not only to show the translation of a gamepad to USB, but also to show how to successfully develop a USB peripheral using the PIC16C765. An understanding of USB descriptors is the foundation for successful USB peripheral development.

Note:	This Technical Brief is the first in a series of five technical briefs. This series is meant to familiarize developers with USB. For the best understanding of USB, read the briefs in order: TB054, TB055, TB056, TB057, TB058

USB BASICS

All USB communication takes the form of frames sent over the USB bus. *Frames* are one millisecond increments in which the host schedules what device endpoints it will communicate with. At the scheduled time, the host and device send one another requests or data in the form of *packets*, which are limited in length to eight bytes for low speed devices. All packets are sent to and received by the device via endpoints. *Endpoints* are buffers where a device either puts data to wait for a chance to be sent to the host, or where data received from the host is stored until the device has a chance to access the data and utilize it. Low speed devices have two endpoints that can be configured by the device as IN or OUT endpoints (with respect to the host). These are Endpoints 1 and 2. Endpoint 0 is an endpoint reserved for control transfers between the host and device. This is the bi-directional avenue through which the host and device share administrative data. *Enumeration*, the process in which a peripheral describes what type of device it is to the host, occurs via Endpoint 0.

USB is a master-slave protocol. In other words, the host (i.e., PC) directs all communications to and from the peripherals. Peripherals do not send information to the host unless the host requests the information. How, then, does a peripheral tell the host what type of device it is when it is first connected to the host? The answer lies in the use of "descriptors," as described in the following section.

DESCRIPTORS

GENERAL

USB descriptors tend to be the biggest stumbling block for developers that have been recently introduced to USB. The purpose of descriptors is to communicate the identity of a particular peripheral to the host. For instance, the gamepad in this Technical Brief communicates to the host that it is a two axis, six-button gamepad that sends data to the host via Endpoint 1. A device doesn't just volunteer this information to the host. Rather, the host requests this information when it detects that a new device has been attached to the USB bus. As mentioned before, this process in which the host requests and receives a device's descriptors, is called "enumeration."

Peripherals have more than one descriptor. Each new descriptor progressively provides the host more information about the peripheral or about other descriptors to follow. Descriptors can be thought of as a hierarchy. The first descriptor, the device descriptor, is very general and conveys the most basic information about the device. The next descriptor is more specific, and so on, until the host has finally gained all the information it needs to communicate effectively with the device.

Gamepads fall under the Human Interface Device (HID) class. Mice, keyboards, and LED displays are all examples of other devices that fall into the HID class. The HID class is unique in that driver support is supplied automatically by Windows® (Windows 98 second edition and newer) and the Macintosh® operating system. These operating systems will custom build a driver whenever they detect a new HID peripheral. The driver is constructed from the data format conveyed in the report descriptor received from that device. Developing within the HID class specification is the easiest way to learn how USB works because the developer doesn't have to be concerned with writing a driver at the host end.

TYPES

Descriptors general to USB are discussed in Chapter 9 of the USB Specification v1.1. The general descriptors that pertain to all USB devices are the following:

- Device
- Configuration
- Interface
- Endpoint

A *device descriptor* describes the most general information about a USB device. For instance, it communicates to the host the product and vendor ID numbers. It tells the host how many configurations the device has, and thus how many configuration descriptors the host must request from the device. A device can have only one device descriptor.

A *configuration descriptor* describes information about a specific device configuration. Included in the configuration descriptor is the number of interfaces under the specific configuration. In essence, an interface is a feature. Therefore, a configuration can be viewed as a collection of peripheral features. Multiple configurations can exist for one device. For instance, if a Power Save mode is desired for a part, it may have two configurations - Normal mode and Power Save mode.

An *interface descriptor* tells how many endpoints a device feature uses. It also declares the class identity of a device. For the gamepad, the class identity is HID.

An *endpoint descriptor* describes the properties of an endpoint. These properties are namely whether the endpoint is an IN or OUT endpoint and what the endpoint number is. Every endpoint specified in an interface has its own endpoint descriptor.

Descriptors specific to the HID class are discussed in the *Device Class Definition for HID* document. The HID descriptors that pertain to describing the gamepad are the following:

- HID
- Report

For a Human Interface Device, a HID descriptor immediately follows the interface descriptor and precedes the endpoint descriptor(s). This is done because the HID descriptor may be associated with more than one endpoint, and as a result, is higher in the "descriptor hierarchy" than endpoint descriptors. A HID descriptor identifies additional descriptors specific to the HID class, namely report descriptors and physical descriptors.

Note:	The gamepad example does not have a physical descriptor associated with it. Physical descriptors are never necessary. They are used to describe the physical aspects and appearance of a device mainly for an engineer's reference.

A *report descriptor* specifies the data format for a device. The information that each bit represents in a data packet is defined in the report descriptor. For instance, for the gamepad certain bits correspond to the logic output of its buttons. Other bit groupings correspond to the X and Y axis positions of the directional pad.

Note:	The *USB Implementers Forum (www.usb.org)* is the main web location for obtaining the USB Specification, Device Class Definition for HID, HID Usage Tables, and all other defining documents pertaining to USB. *USB Complete*, written by Jan Axelson, presents the USB protocol in a easy to understand format.

THE GAMEPAD REPORT

The device, configuration, interface, HID, and endpoint descriptors are relatively straightforward to create. For these descriptors all that is necessary is to create the descriptors according to the definitions in the USB or HID specifications. The report descriptor, however, is not straightforward. There is no set format for a report descriptor since it is describing the data format for a peripheral which can be very different from one peripheral to another. The best way to learn how to create a report descriptor is to walk through example report descriptors that have been proven to work. Example 0-1 shows the report descriptor for the gamepad.

> **Note:** Microchip provides a USB Descriptor Wizard to help speed the creation of the device, configuration, interface, and endpoint descriptors. This tool is available at: www.microchip.com

EXAMPLE 1: USB Gamepad Report Descriptor

```
0x05, 0x01              ; USAGE_PAGE (Generic Desktop)
0x09, 0x05              ; USAGE (Gamepad)
0xA1, 0x01              ; COLLECTION (Application)
0x09, 0x01              ;   USAGE (Pointer)
0xA1, 0x00              ;   COLLECTION (Physical)
0x09, 0x30              ;     USAGE (X)
0x09, 0x31              ;     USAGE (Y)
0x15, 0x00              ;     LOGICAL_MINIMUM (0)
0x26, 0xFF, 0x00        ;     LOGICAL_MAXIMUM (255)
0x75, 0x08              ;     REPORT_SIZE (8)
0x95, 0x02              ;     REPORT_COUNT (2)
0x81, 0x02              ;     INPUT (Data,Var,Abs)
0xC0                    ;   END_COLLECTION
0x05, 0x09              ;   USAGE_PAGE (Button)
0x19, 0x01              ;   USAGE_MINIMUM (Button 1)
0x29, 0x06              ;   USAGE_MAXIMUM (Button 6)
0x15, 0x00              ;   LOGICAL_MINIMUM (0)
0x25, 0x01              ;   LOGICAL_MAXIMUM (1)
0x75, 0x01              ;   REPORT_SIZE (1)
0x95, 0x06              ;   REPORT_COUNT (6)
0x81, 0x02              ;   INPUT (Data,Var,Abs)
0x95, 0x02              ;   REPORT_COUNT (2)
0x81, 0x03              ;   INPUT (Constant,Var,Abs)
0xC5                    ; END_COLLECTION
```

THOUGHT PROCESS FOR DEVELOPING THIS DESCRIPTOR

The following is the thought process for developing this descriptor. Please refer to the *HID Usage Tables* for a complete list of Usage Pages and Usages. (See references at the end of this Tech Brief).

The first thing to do is to tell the host that the device is a gamepad. To do this, it is necessary to declare "USAGE (Gamepad)" or "0x09, 0x05" numerically. Before doing this, however, the appropriate page that “Gamepad” is listed as a Usage on must be referenced. Looking gamepad up in the HID Usage Tables reveals that the appropriate Usage Page is Generic Desktop. Once this Usage Page is declared, Usage Gamepad is specified. When the host has this information, it knows to add this device to the game controller category of its device listing. As a result, the gamepad can be calibrated using the game controller calibration program provided with the host's operating system.

All report descriptors must have an Applications Collection. This Collection specifies the sources of I/O for the device and the format that the I/O is reported to the host. The Usage item that follows the Applications Collection specifies the general function of the collection. In this case the Usage that follows is Pointer. Pointer is a Usage on the Generic Desktop Usage Page. It is not necessary to specify the Generic Desktop Usage Page again.

Note:	The Usage Page must be specified only if the Usage that follows is not on the existing Usage Page.

The D-pad on the gamepad controls two axis, X and Y. Because each axis has the same characteristics in terms of data report format, these axes can be grouped into a Collection. The X-axis and Y-axis are physical parameters, therefore the Collection is of type Physical.

After the Collection is initialized, Usages X and Y are declared. Each axis of the D-pad is connected to a potentiometer inside the gamepad. When the D-pad is pressed the potentiometer varies the voltage on a wire connected to one of the A-to-D ports on the PIC16C765. Therefore, the PICmicro MCU will see a digital value coming from each axis in the range of 0 to 255. The Logical Minimum and Logical Maximum correspond to this range. Eight bits are needed to report values in this range - the Report Size reflects this number. Two reports are needed, one for the X-axis and one for the Y-axis. The Report Count reflects this number. These two bytes are then designated as data inputs to the host with Input (Data, Variable, Absolute). Finally, the Collection is closed with the item End Collection.

The gamepad has six buttons. A Physical Collection could be made and all the buttons listed as Usages (i.e. Usage {Button 1}, Usage {Button 2}, etc.) similar to what was done with the X and Y axis. However, the easier way to make a list of buttons is to use the Usage Minimum and Usage Maximum items on the Buttons Usage Page. Each button accounts for a logical bit as reflected by the:

- Logical Minimum,
- Logical Maximum, and
- Report Size

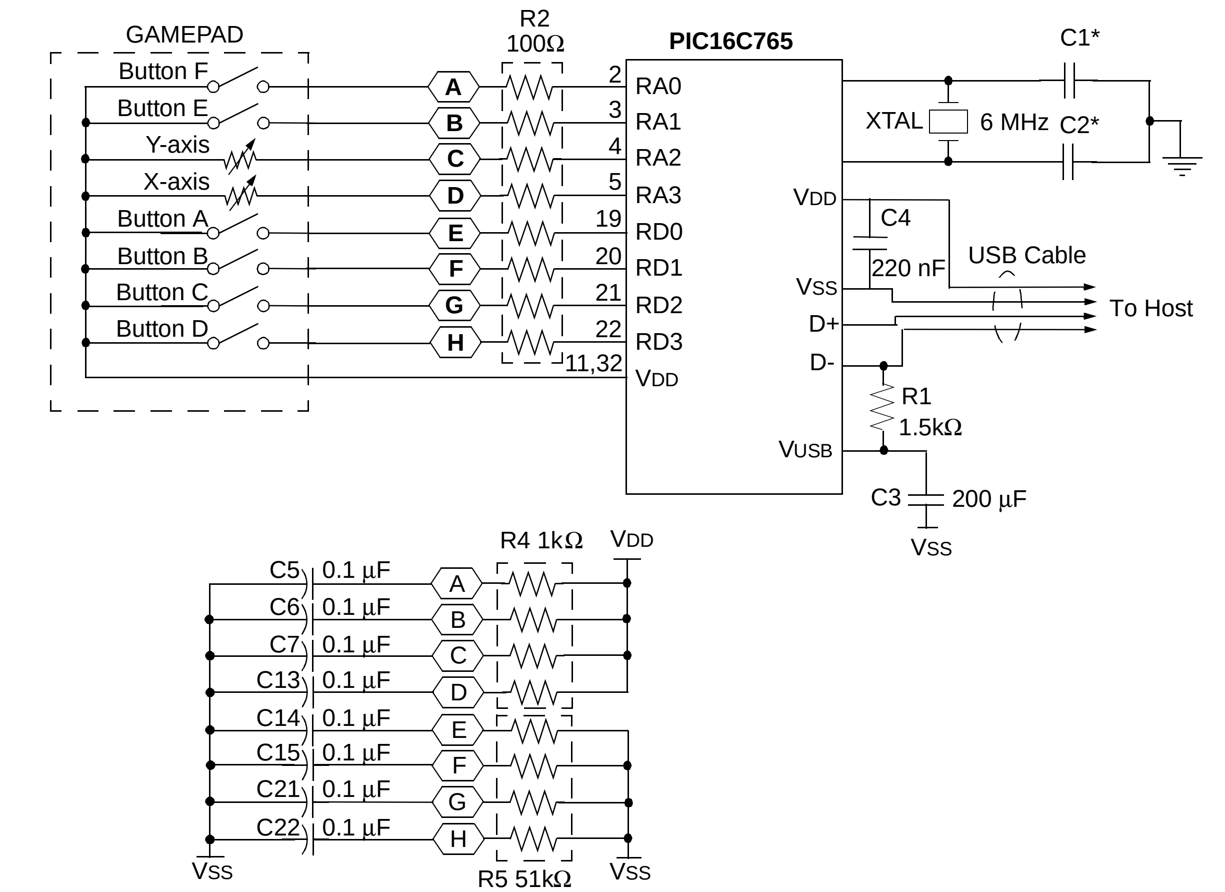
The Report Count is six, corresponding to the number of buttons. These six bits are then input as data with the Input item. Data sent over the USB bus must be sent as blocks of whole bytes. The six button report bits are two bits short of a byte. Therefore, a Report Count of two is specified and these bits are input as Constants with the Input item. The entire Application Collection is closed with the End Collection item.

IMPLEMENTATION

HARDWARE

The specific gamepad used in this technical brief is the Dexxa™ eight-button (six actual as seen by the host) gamepad. This gamepad connects to the standard gameport on a PC. A PC gameport has four pins designated for analog inputs and four pins for digital inputs. Each axis of the D-pad uses an analog pin to send its position to the host. The remaining analog and digital pins are utilized by the six gamepad buttons. Although two of the buttons are connected to analog pins their inputs are digital, either high or low. The following circuit diagram shows how the PICmicro MCU is wired as a translator between the gameport and PC.

FIGURE 1: USB GAMEPAD CIRCUIT DIAGRAM



Note: Microchip's PICDEM™ USB board was used to develop the USB gamepad. This board has all the external circuitry necessary in place.

***Note:** C1 and C2 values selected according to crystal load capacitance.

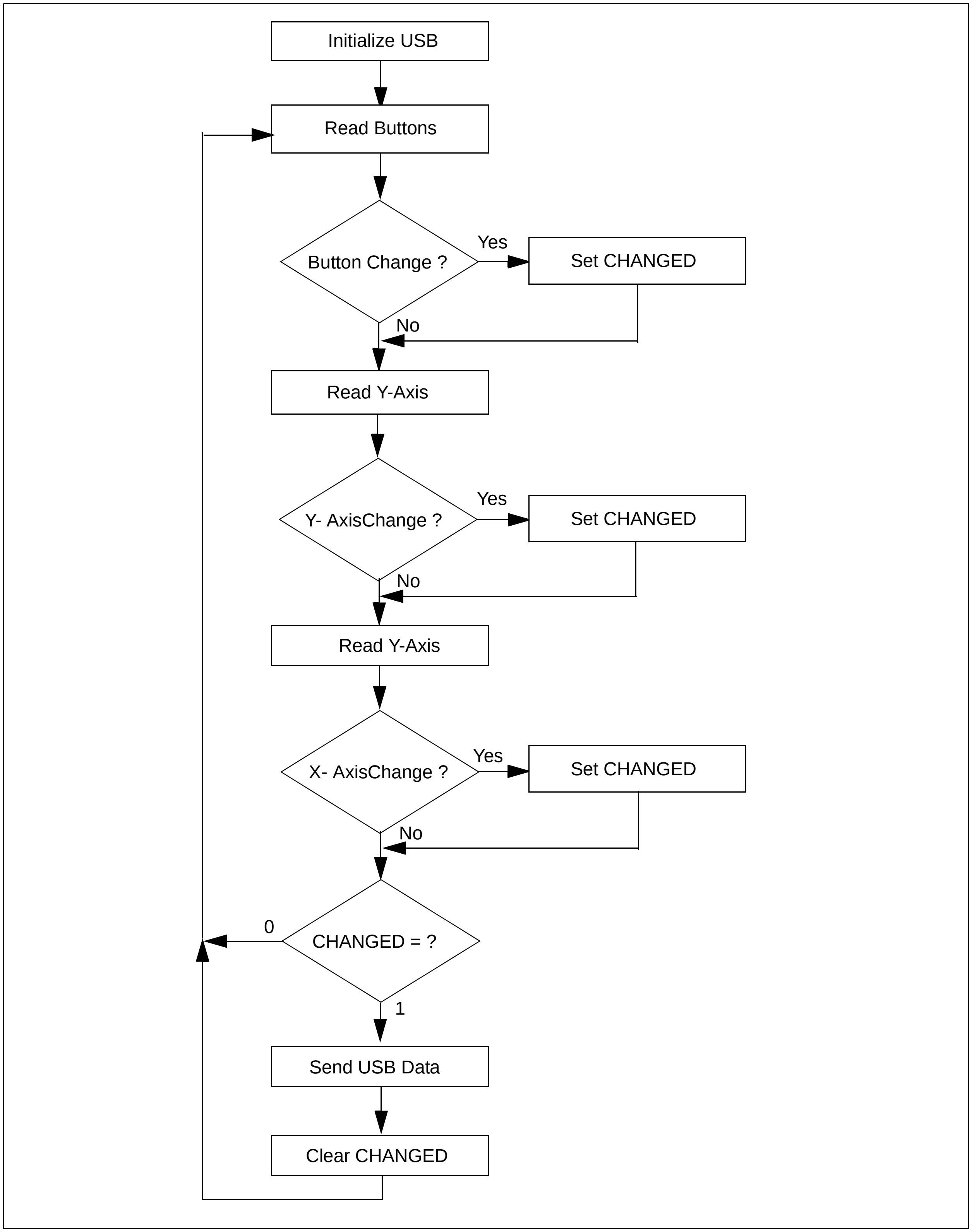
From Figure 1 it can be seen that the analog pins have several external components added between the gamepad and PICmicro MCU, namely two resisters and one capacitor per pin. The reason for this circuitry stems from the way analog pins were originally read by the PC. The PC would clear a capacitor tied to ground at its end and then time how long it took the capacitor to charge up. The capacitor would charge at a rate proportional to the resistance varied by one axis of the joystick, for instance. This is legacy technology and is not needed when using a PICmicro MCU with an analog-to-digital converter. As a result, the before-mentioned circuitry was put into place in order to obtain a clean analog output from the D-pad. This circuitry is not needed for buttons E and F since they are digital, but was put in place so that this diagram will support other gamepads.

SOFTWARE

Microchip's USB support firmware provided a foundation for creating the USB gamepad firmware. The firmware provides a linkable file named `ch9_usb.asm`, which includes most of the functions described in Chapter 9 of the USB Specification, v1.1. Also included with this firmware is the file `hidclass.asm`. This file implements functions described in the *HID Device Class Definitions*. These two files were linked without any changes to the USB gamepad project. The two remaining assembly files included with the Chapter 9 USB firmware, `descript.asm` and `main.asm`, were altered to implement the gamepad conversion.

The USB support firmware has a cursor demonstration incorporated into it. The file `descript.asm` contains the descriptors necessary for the demonstration to enumerate properly. To convert this file for the gamepad application the cursor demonstration descriptors were removed and replaced with the gamepad descriptors. `Main.asm` was rewritten to contain the main routine for the gamepad conversion. The main program flow is shown in Figure 2.

FIGURE 2: MAIN ROUTINE BLOCK DIAGRAM



CONCLUSION

For engineers just introduced to USB, descriptors pose a hurdle that is time-consuming to overcome. Walking through the conversion of the gamepad from the game-port interface to USB is a very effective way of overcoming this hurdle. Although most of the PIC16C765's resources are unused for the USB gamepad, this technical brief serves as a starting place for developing more complex USB peripherals using the PIC16C745 or PIC16C765.

MEMORY USAGE

In the PIC16C765, the following memory was used:

Data Memory	50 Bytes
Program Memory:	1.9K Bytes

REFERENCES

1. *USB Specification*, Version 1.1: Chapter 9 (located at www.usb.org)
2. *Device Class Definition for Human Interface Devices* (located at www.usb.org)
3. *HID Usage Tables* (located at www.usb.org)
4. *USB Firmware User's Guide* (located in USB Support Firmware zip file at www.microchip.com)
5. *USB Complete, Second Edition,* Jan Axelson; Lakeview Research, 2001 (www.lvr.com)
6. TB055: *PS/2 to USB Mouse Translator*
7. TB056: *Demonstrating the Set_Report Request with a PS/2 to USB Keyboard Translator Example*
8. TB057: *USB Combination Devices Demonstrated by a Combination Mouse and Gamepad device*
9. TB058: *Demonstrating the Soft Detach Function with a PS/2 to USB Translator Example*

APPENDIX A: SOURCE CODE

Due to the length of the source code for the Gameport to USB Gamepad Translator example, the source code is available separately. The complete source code is available as a single WinZip archive file, tb054sc.zip, which may be downloaded from the Microchip corporate Web site at:

www.microchip.com

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- The PICmicro family meets the specifications contained in the Microchip Data Sheet.
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