AN1189

Implementing a Mass Storage Device Using the Microchip USB Device Firmware Framework

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INTRODUCTION

USB devices are now part a daily life for many people throughout the world. Removable USB hard drives, USB memory sticks (“thumb drives”), multi-card readers and many digital cameras appear as a new disk drive when they are plugged into the USB port of a computer. These devices all use the Mass Storage Device (MSD) class to communicate with the computer.

This application note will cover how to modify the Microchip USB Device Firmware Framework to create a Mass Storage Device. It is assumed that the user already has some working knowledge of the USB protocol.

BACKGROUND ON THE MASS STORAGE DEVICE CLASS

Disk drive manufacturers have been creating compatible disks for over two decades now. The Small Computer System Interface (SCSI) protocol was developed during this time, allowing drive manufacturers and system developers to share a common protocol for device control and communication. SCSI provides the means for reading, writing and checking the status of the drives, as well as other available commands.

The USB Implementers Forum (USB-IF) re-used the existing SCSI protocols to create a new physical interface for mass storage applications. The USB Mass Storage Device class is the result of that effort. The MSD class specification uses the already existing protocols and provides a wrapper around them in order to transport them over the USB. For external hard drives or thumb drives, this is the SCSI protocol. By using the same protocols as other drives, this enables MSD devices to appear on the host as a new disk drive.

The MSD protocol has two types of command packets: the Command Block Wrapper (CBW) at the beginning of a data transaction, and the Command Status Wrapper (CSW) at the conclusion. If data is exchanged between a host and device, it occurs between these after the Command Block Wrapper and before the Command Status Wrapper.

The CBW is transmitted on the USB as the first packet of a new transaction. It defines what command is being transmitted, what the length is, which logical device is being talked to and a tag to help tie the command to a status stage.

After the CBW is received by the device, there may or may not be a data transmission phase. This depends on what the command was and if it required a data stage. For example, if the command was a SCSI READ(10) command, then the device should read and return the requested addresses during the data transmission phase.

After all of the data has been sent, the USB host closes out the entire transaction by sending a CSW packet. This packet has a tag that matches the corresponding CBW. The CSW also contains a residue field that informs the host about any requested data that may have not been sent during that transaction. Finally, there are status bits that are sent back to indicate if there were any errors while performing the requested function.

More information about each field of the CBW and CSW packets is available in the MSD specification, available at the USB-IF web site (www.usb.org).

MASS STORAGE DEVICE FIRMWARE

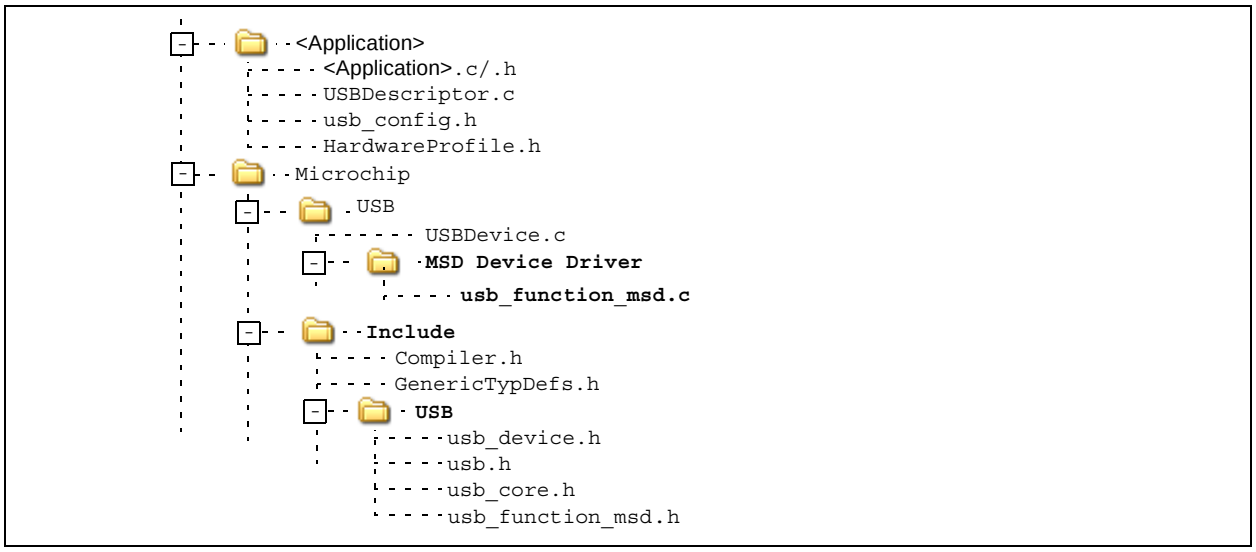
The Microchip USB Device Firmware Framework provides an MSD class driver that can be used to easily create MSD devices. Several example projects are provided as a reference starting point. Please refer to the help file provided in the USB Device Firmware Framework distribution for more details about these example projects. The following section provides details in how to take the base USB Device Firmware Framework and create a working MSD example with the provided class driver.

Directory Structure

The MSD class driver is included in the USB Device Firmware Framework installation; the directory structure is shown in Figure 1. The USB files required for an MSD application (shown in **bold**) must be included in the project.

The entire MSD class driver is contained in the files, `usb_function_msd.c` and `usb_function_msd.h`.

FIGURE 1: PROJECT DIRECTORY STRUCTURE FOR MSD PROJECTS



Physical Layer

The MSD class driver was written to use the physical layers provided in the Microchip Application Note *AN1045, "Implementing File I/O Functions Using Microchip's Memory Disk Drive File System Library"*.

Once the physical layer is installed, the MSD code needs to know where to find the physical interface functions. For this purpose, there are several application-specific definitions that must be defined by the application:

- `LUNMediaInitialize()`
- `LUNReadCapacity()`
- `LUNReadSectorSize()`
- `LUNMediaDetect()`
- `LUNSectorWrite(bLBA,pDest,Write0)`
- `LUNWriteProtectState()`
- `LUNSectorRead(bLBA,pSrc)`

An example definition would look like: `#define LUNMediaInitialize() MediaInitialize()`.

Within the source code for the Memory Disk Drive File System, only the physical layer files need to be added (e.g., `sd_card.c` and `sd_card.h`); system files (e.g., `FSIO.c`) are not required. Please see the examples accompanying the file system code for more details.

Functions

There are three additional function calls that are required by the MSD class driver. The first is the initialization function, `USBMSDInit()`. This function should be called when the device is plugged into the USB port. This can be added into `USBCBInitEP`, as shown in Example 1. If an application requires that both the USB host and the embedded device be able to modify the media content, then the system files are required.

The second function is `MSDTasks()`. This is the main task handler for the MSD device driver. This function should be called frequently while the device is connected to the USB, but only after the USB is in a configured state. The frequency at which this function is called helps to determine the device throughput. Example 2 shows a typical usage.

Note:	When using the MSD class, please insure that the data contents are not being modified while the host is attempting to read/write the data. Use a semaphore or some other mechanism to manage both sets of code accessing the same memory.

EXAMPLE 1: TYPICAL USAGE OF `USBMSDInit()`

```
void USBCBInitEP(void)
{
    USBEnableEndpoint(MSD_DATA_IN_EP,
       USB_IN_ENABLED|USB_OUT_ENABLED|USB_HANDSHAKE_ENABLED|USB_DISALLOW_SETUP);
    USBMSDInit();
}
```

EXAMPLE 2: TYPICAL USE OF `MSDTasks()`

```
void ProcessIO(void)
{
     if((USBDeviceState < CONFIGURED_STATE)||(USBSuspendControl==1)) return;
     MSDTasks();
}//end ProcessIO
```

The final function that needs to be called is USBCheckMSDRequest(). This function checks transactions on Endpoint 0 to see if they apply to the MSD class driver. This function can be called from the function, USBCBCheckOtherReq(), as shown in Example 3.

EXAMPLE 3: TYPICAL USE OF USBCheckMSDRequest()

```
void USBCBCheckOtherReq(void)
{
    USBCheckMSDRequest();
}                           //end
```

Definitions and Constants

The physical layer section of this document already covered some definitions that are required to tie a physical interface to the MSD class driver. There are a few other definitions and constants that need to be added or changed in order to get the MSD class driver to work with the USB firmware framework.

DESCRIPTORS

When any USB device is attached to the bus, it is required to send a set of descriptors that tell the computer host what type of device it is. For most device classes, this is typically done through the bDeviceClass, bDeviceSubClass and bDeviceProtocol fields of the device descriptor (see Table 9-8 of the USB specification for more details). The MSD class driver, however, requires that MSD devices declare their class in the interface descriptor and leave these fields in the device descriptor as unspecified (0x00), as shown in Example 4.

Inside the interface descriptor, there are three fields that must be updated to use the MSD class driver. The bInterfaceClass, bInterfaceSubClass and bInterfaceProtocol need to be updated to the correct values. The bInterfaceClass field needs to reflect that this device is an MSD device (MSD_INTF). The bInterfaceSubClass needs to reflect which of the subclasses defined in the MSD specification that the application is using. The options available can also be found in the file, usb_function_msd.h. All of the demo applications have MSD_INTF_SUBCLASS defined as SCSI_TRANSPARENT so that the host uses the SCSI command set to talk to the device.

The bInterfaceProtocol must reflect which MSD protocol method is being used for data transfer. All new applications are required to use the Bulk Only Transport (BOT) protocol. This protocol uses one bulk endpoint for data from the host, one bulk endpoint for data going to the host and the control endpoint for other control related transfers. For this purpose, the MSD_PROTOCOL should be set to BOT (0x50).

In addition to the updated interface fields, the endpoint descriptors, located at the end of the configuration descriptor, are updated, such that there is one bulk IN endpoint and one bulk OUT endpoint. A typical MSD configuration descriptor with all the required changes is shown in Example 5.

EXAMPLE 4: DEVICE DESCRIPTOR FOR MASS STORAGE DEVICE (CLASS, SUBCLASS AND PROTOCOL UNSPECIFIED)

```
/* Device Descriptor */
ROM USB_DEVICE_DESCRIPTOR device_dsc=
{
    0x12,                   // Size of this descriptor in bytes
    USB_DESCRIPTOR_DEVICE,  // DEVICE descriptor type
    0x0110,                 // USB Spec Release Number in BCD format
    0x00,                   // Class Code
    0x00,                   // Subclass code
    0x00,                   // Protocol code
    EP0_BUFF_SIZE,          // Max packet size for EP0, see usbcfg.h
    0x04D8,                 // Vendor ID
    0x0009,                 // Product ID: mass storage device demo
    0x0001,                 // Device release number in BCD format
    0x01,                   // Manufacturer string index
    0x02,                   // Product string index
    0x00,                   // Device serial number string index
    0x01                    // Number of possible configurations
};
```

EXAMPLE 5: CONFIGURATION DESCRIPTOR FOR MASS STORAGE DEVICE

```
/* Configuration 1 Descriptor */
ROM BYTE configDescriptor1[]=
{
    /* Configuration Descriptor */
    9,                                  // Size of this descriptor in bytes
    USB_DESCRIPTOR_CONFIGURATION,       // CONFIGURATION descriptor type
    0x20,0x00,                          // Total length of data for this cfg
    1,                                  // Number of interfaces in this cfg
    1,                                  // Index value of this configuration
    0,                                  // Configuration string index
    _DEFAULT|_SELF,                     // Attributes, see usbdefs_std_dsc.h
    50,                                 // Max power consumption (2X mA)

    /* Interface Descriptor */
    9,                                  // Size of this descriptor in bytes
    USB_DESCRIPTOR_INTERFACE,           // INTERFACE descriptor type
    0,                                  // Interface Number
    0,                                  // Alternate Setting Number
    2,                                  // Number of endpoints in this intf
    MSD_INTF,                           // Class code
    MSD_INTF_SUBCLASS,                  // Subclass code
    MSD_PROTOCOL,                       // Protocol code
    0,                                  // Interface string index

    /* Endpoint Descriptor */
    7,
    USB_DESCRIPTOR_ENDPOINT,
    _EP01_IN,_BULK,
    MSD_IN_EP_SIZE,0x00,
    0x00,

    7,
    USB_DESCRIPTOR_ENDPOINT,
    _EP01_OUT,
    _BULK,
    MSD_OUT_EP_SIZE,0x00,
    0x00
};
```

INQUIRY RESPONSE STRING

One of the SCSI commands sent to the MSD device is `INQUIRY`. This asks the device for information, such as if the device is removable, which SCSI command sets does this device support and various strings that are used to label the drive in the operating system. The MSD class driver looks for a reference inside the code defined as `const ROM InquiryResponse inq_resp[]` that should hold this data. This string should be defined inside the user code. An example for a Mass Storage Device is shown in Example 6.

There are three fields that need to be modified in this structure. The first is the T10-assigned Vendor ID, provided by the INCITS Technical Committee that oversees the standards for SCSI storage devices. Each vendor of a SCSI storage product should have a unique T10 Vendor ID, in addition to the Vendor ID assigned by the USB-IF. Users can obtain more information about the T10 Vendor ID (available without cost at the time of this writing) at the committee's web site (www.t10.org).

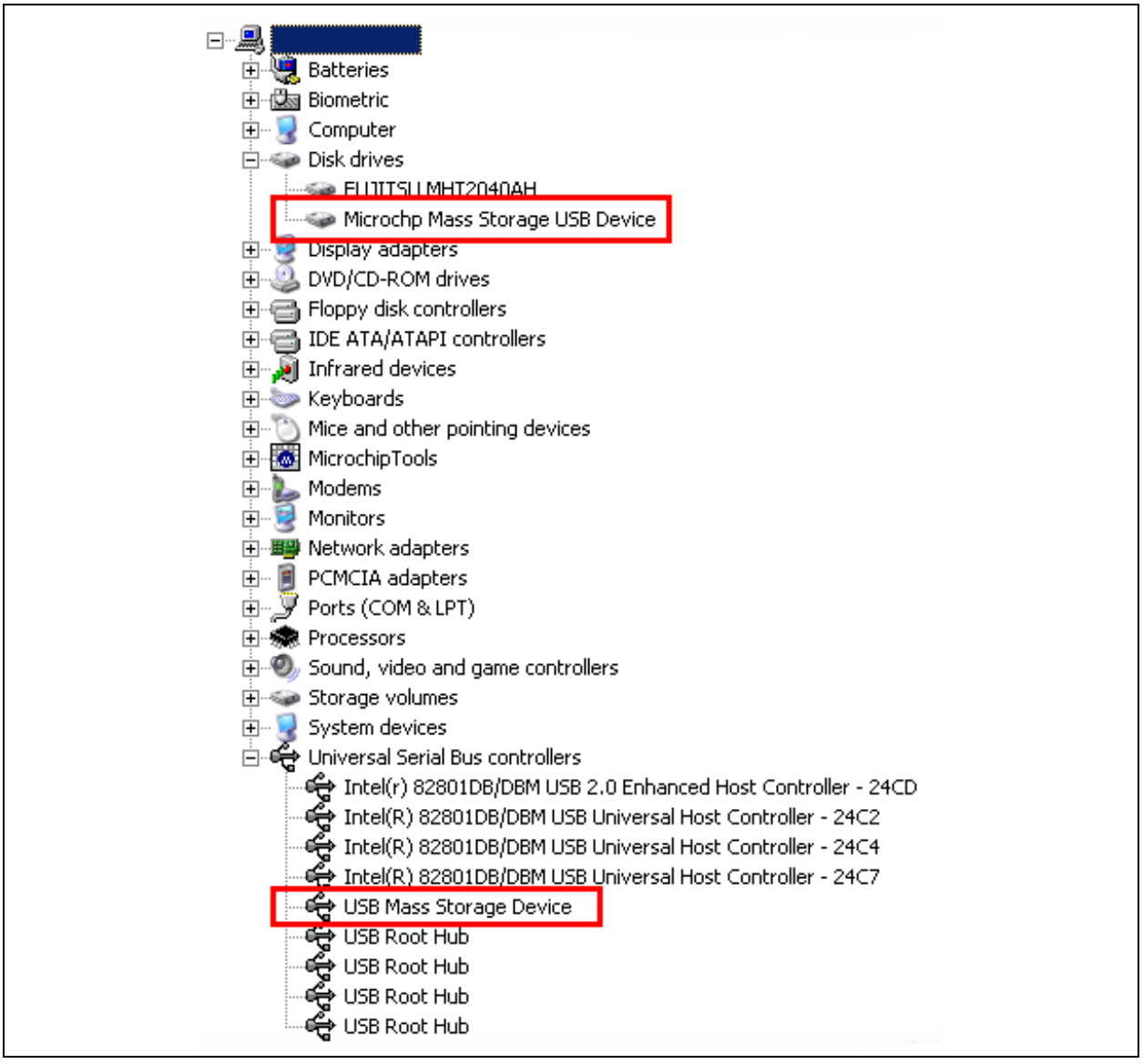
The product ID and revision information files can be modified as desired by the vendor. They are fixed length strings, so any unused locations need to contain spaces.

Figure 2 shows the Device Manager window for a host connected to a device with the inquiry response string shown in Example 6 (upper red box). Note how the string in the disk drive section reflects the names returned in the response. The name provided in the USB section of the Device Manager (second red box) is a generic string that is provided for all USB MSD devices.

EXAMPLE 6: MSD INQUIRY RESPONSE STRING

```
/* Standard Response to INQUIRY command stored in ROM */
const ROM InquiryResponse inq_resp = {
       0x00,  // peripheral device is connected, direct access block device
       0x80,  // removable
       0x04,  //, 4=> SPC-2
       0x02,  // response is in format specified by SPC-2
       0x20,  // n-4 = 36-4=32= 0x20
       0x00,  // sccs etc.
       0x00,  // bque=1 and cmdque=0,indicates simple queueing
       0x00,  // 00 obsolete, 0x80 for basic task queueing
       {'M','i','c','r','o','c','h','p'},   // T10-assigned Vendor ID
       {'M','a','s','s',' ','S','t','o','r','a','g','e',' ',' ',' ',' '}, //product ID
       {'0','0','0','1'}                    //revision information
};
```

FIGURE 2: MASS STORAGE DEVICE AS IT APPEARS IN DEVICE MANAGER



`usb_config.h` Settings

There are several additional settings that must be defined in order for the MSD class firmware to run correctly. These settings (Example 7) should be added to the `usb_config.h` file located in the application directory of the user's program.

First, the MSD class library needs to be enabled. This is done by defining `USB_USE_MSD`. In addition, the MSD class firmware must know which endpoints have been selected in the descriptors to use as the MSD endpoints. In this example, Endpoint 1 was used for the in and out data. The firmware must also know the size of the endpoints used for the MSD data transfer.

Finally, the MSD class firmware needs to know how many Logical Unit Numbers (LUNs) the device supports. The number of logical units is the number of drives that the application wishes to show up for this USB device. This value is 0 through 15 inclusive, indicating the maximum Logical Unit Number (LUN) of the system. If the system has only one logical unit, then 0 must be used. Up to 16 LUNs can be defined.

Memory Organization and Linker File Modifications for PIC18 Devices

The MSD class library transfers an entire sector of data (typically, 512 bytes) at a time. For this reason, a sector size array is required in the MSD class firmware.

In PIC18 devices, the maximum data size that is allowed in a single bank of RAM is 256 bytes. Data variables that are larger than this require modifications to the device's linker script. This data must reside in RAM that is also accessible by the USB module. The newly formed 512-byte section must be named `myMSD`.

Example 8 shows a typical PIC18F4550 linker script with the required modifications. Note that the "`usb6`" and "`usb7`" data memory sections are commented out and the new `myMSD` data bank spans the memory that was in both of these banks.

EXAMPLE 7: MSD DEFINITIONS ADDED TO `usb_config.h`

```
#define USB_USE_MSD                 // enable MSD Class library
#define MSD_DATA_IN_EP1             // use EP1 for input data
#define MSD_DATA_OUT_EP1            // and output data
#define MSD_IN_EP_SIZE 64           // endpoint sizes in bytes
#define MSD_OUT_EP_SIZE 64          //
#define MAX_LUN 0                   // only one LUN will be supported
```

EXAMPLE 8: TYPICAL PIC18 LINKER SCRIPT FOR USE WITH MSD

```
ACCESSBANK     NAME=accessram START=0x0      END=0x5F
DATABANK       NAME=gpr0      START=0x60     END=0xFF
DATABANK       NAME=gpr1      START=0x100    END=0x1FF
DATABANK       NAME=gpr2      START=0x200    END=0x2FF
DATABANK       NAME=gpr3      START=0x300    END=0x3FF
DATABANK       NAME=usb4      START=0x400    END=0x4FF  PROTECTED
DATABANK       NAME=usb5      START=0x500    END=0x5FF  PROTECTED
//DATABANK     NAME=usb6      START=0x600    END=0x6FF  PROTECTED
//DATABANK     NAME=usb7      START=0x700    END=0x7FF  PROTECTED
DATABANK       NAME=myMSD     START=0x600    END=0x7FF  PROTECTED
ACCESSBANK     NAME=accesssfr START=0xF60    END=0xFFF  PROTECTED
```

FREQUENTLY ASKED QUESTIONS ABOUT THE MSD FIRMWARE

Q: I am missing the physical interface files (`SD-SPI.c`, `SD-SPI.h`, etc.). Where can I find them?

A: These files are located in the installation for Microchip Application Note *AN1045, "Implementing File I/O Functions Using Microchip's Memory Disk Drive File System Library"*. Install the files from AN1045 into the same base directory as the USB device firmware framework.

Q: How do I get a MSD device working in conjunction with the Microchip MDD library in AN1045?

A: In addition to the physical layer and configuration files, the file system files (`FSIO.c`, `FSIO.h`, etc.) are required. These files are only required when both the USB host and the firmware want to read and/or modify the contents of the memory on the drive. If only the USB host reads and/or writes the memory, then these files are not required. Also, depending on the system implementation, it may be required to create a semaphore system to prevent the USB code and the MDD code from accessing the physical media simultaneously, as corruption of the disk may result if the host and embedded device try to write to the media at the same time. Please see the provided demo for an example project.

Q: What is "T10" and why does my device need a T10 Vendor ID?

A: "T10" is shorthand for Technical Committee 10 of the International Committee on Information Technology Standards (INCITS). INCITS is an ANSI accredited body that develops voluntary standards for information technology; T10 is the specific group that maintains the Small Computer System Interface (SCSI) storage standards.

The T10 Vendor ID is used during device enumeration to help users correctly identify a particular device in the host operating system. Unlike a USB-IF Vendor ID, the T10 Vendor ID is not required for a device to be offered for sale. Manufacturers also do not have to belong to T10 to obtain a Vendor ID. As of the time of this document's publication, there is no cost to register a T10 ID.

Additional information on T10 and the Vendor ID registration process is available at the committee's web site, www.t10.org.

Q: Why does the device name show up as "Microchp" in the Windows® Device Manager? Is this a typographical error?

A: This is not a typo, but the best answer to a technical limitation. Since the Vendor ID field sent in response to the `INQUIRY` command can only be 8 bytes long, "Microchp" is used as a shortened version of Microchip (which would be 9 bytes).

Q: Why doesn't MSD work with Microsoft® Windows 98?

A: The MSD demonstration uses the native Windows driver, `usbstor.sys`. The Windows 98 operating system does not provide native support for the driver. Please refer to the Microsoft web site for details:

http://www.microsoft.com/whdc/device/storage/usbfaq.mspx

Q: Why does MSD implement the SCSI command set and not the RBC?

A: Currently, Windows 2000 and Windows XP do not provide support to handle devices that implement Reduced Block Commands (RBC, subclass 0x01) protocol. Please refer to the Microsoft web site for further details:

http://www.microsoft.com/whdc/device/storage/usbfaq.mspx

SUMMARY

Developing a USB Mass Storage Device application is no different, and no more complicated, than developing any other USB device application. Using the Microchip USB Device Firmware Framework and accompanying MSD firmware, users can design a solution without having to worry about the underlying SCSI protocols.

This application note covers the basic concepts of creating and configuring an MSD application. Additional examples and demos are included with the Microchip USB Device Firmware Framework for various MSD solutions.

REFERENCES

For more information on components of the Microchip USB Peripheral Device Support Package, the following documents are available at the Microchip web site (www.microchip.com/usb):

- Microchip Application Note *AN1045, "Implementing File I/O Functions Using Microchip's Memory Disk Drive File System Library"* (DS01045)
- *"Microchip USB Device Firmware Framework User's Guide"* (DS51679)

For more information on USB in general:

- USB Implementers Forum, *"Universal Serial Bus Revision 2.0 Specification"*, http://www.usb.org/developers/docs/

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