Using a USB Flash Drive with an Embedded Host

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INTRODUCTION

USB Flash drives are a popular, simple and inexpensive method of moving data from one PC to another. Their use in the embedded market has been limited, however, due to the requirement that a system must have USB host capability to communicate with a Flash drive.

In the past, this usually meant that the system needed to be a PC. However, the introduction of Microchip's PIC® microcontrollers with USB embedded host capability means that embedded systems can now take advantage of this popular portable media. With the ability to store data to a USB Flash drive, a PIC microcontroller-based application now has virtually unlimited data storage.

This application note demonstrates a data logger application that can run on the Explorer 16 Demo Board with the USB PICtail™ Plus Daughter Board. It implements a file system with a simple, but powerful, set of commands.

A Note About USB Flash Drives

USB Flash drives come in a wide variety of shapes and sizes. Many of the Flash drives, with up to 2 GB of memory, utilize the FAT16 file system and a Small Computer System Interface (SCSI) command interface. Microchip Application Note *AN1045, "Implementing File I/O Functions Using Microchip's Memory Disk Drive File System Library"* (DS01045), describes an implementation of this file system.

Note:	Flash drives with more than 2 GB of memory utilize the FAT32 file system, which is not supported by AN1045.

THE DATA LOGGER APPLICATION

This application stores two types of data:

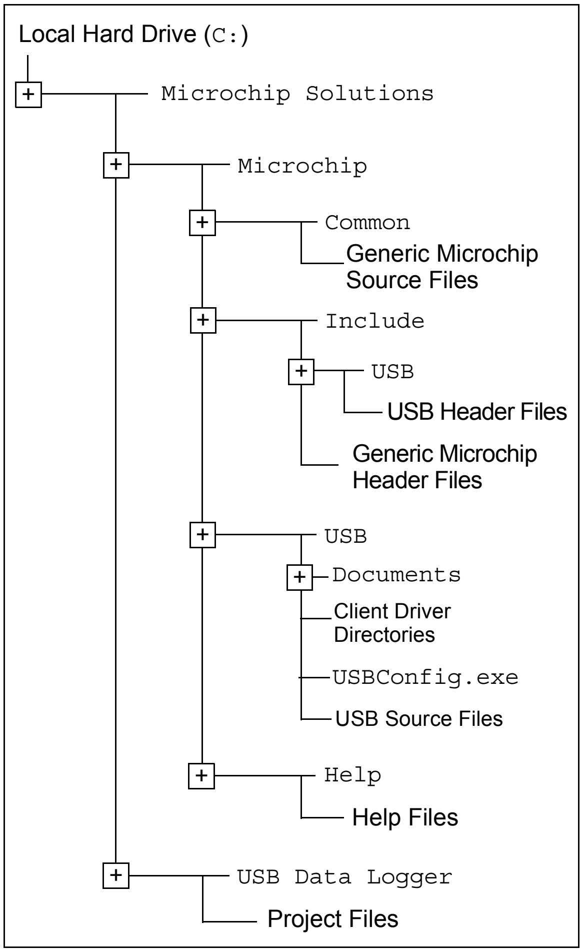
- Low data rate monitoring. This is done by polling the on-board potentiometer approximately once per second. The potentiometer reading and time and date stamp of the reading are saved to a file on the Flash drive.
- Higher speed time measurement accuracy. This is done by reading the temperature sensor every 10 ms. The temperature reading and the count of elapsed milliseconds are saved to a file on the Flash drive.

The application also provides a set of simple commands to interface to the Flash drive (via a serial terminal interface) and directly manipulate files on the Flash drive.

Installing the Stack

The USB data logger application is available as part of Microchip's complete USB Embedded Host Support Package (see **Appendix A: "Software Discussed in this Application Note"** for more details). To install all the necessary project files on a host PC, download the installation file from the Microchip web site and run the executable installer file. By default, the project and Stack files will be installed in the directory structure shown in Figure 1.

FIGURE 1: DEFAULT DIRECTORY STRUCTURE FOR USB EMBEDDED HOST SUPPORT



Application Architecture

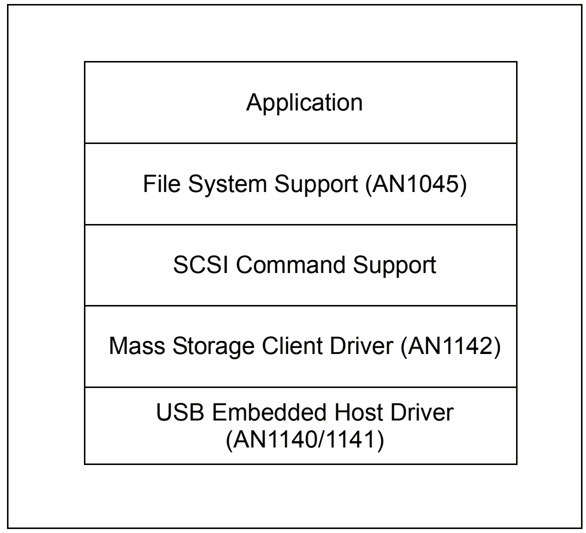
The data logger application is actually a multi-layer Stack (Figure 2), with different components of Microchip's USB Embedded Host Support Package contributing to different layers. Table 1 shows the source files used in this application, and which layer those files implement.

USB EMBEDDED HOST DRIVER

The USB embedded host driver provides generic support for USB embedded hosts. The interface to this layer is provided automatically in the mass storage client driver.

For more information about this layer, refer to Microchip Application Notes *AN1140, "USB Embedded Host Stack"* (DS01140), and *AN1141, "USB Embedded Host Stack Programmer's Guide"* (DS01141). Note that it is not necessary to be familiar with this layer's operation or configuration in order to use it with the data logger application.

FIGURE 2: APPLICATION ARCHITECTURE



MASS STORAGE CLIENT DRIVER FOR USB EMBEDDED HOST

The next layer provides the client driver for the mass storage class, which is required for interfacing with mass storage devices, such as a USB Flash drive. Refer to Microchip Application Note *AN1142, "USB Mass Storage Class on an Embedded Host"* (DS01142), for more information about the mass storage client driver.

FILE SYSTEM AND SCSI COMMAND SUPPORT

The file system support layer is provided by the file system library described in Microchip Application Note AN1045. This application note uses five functions (Table 2) to interface with the hardware. By replacing these low-level functions with SCSI commands that utilize the mass storage client driver for communication, we can use this application note to provide the file system interface to the USB Flash drive.

Note:	For detailed information about the USB Embedded Host Mass Storage SCSI Interface API, please refer to the documentation for the USB Embedded Host Library provided in the Help directory.

TABLE 1: FILES USED FOR THE DATA LOGGER APPLICATION

Layer	File Name	Description
USB Embedded Host Driver	usb_host.c	Provides USB embedded host support for all devices. Does not provide class support.
	usb_host.h	Header file with definitions required for USB embedded hosts. Defines the interface to the USB embedded host driver.
	USBCore.h	Header file with definitions common to both USB embedded hosts and USB peripherals
Mass Storage Client Driver	usb_host_msd.c	Provides mass storage class support for a USB embedded host.
	usb_host_msd.h	Header file with definitions for USB embedded hosts supporting the mass storage class. Defines the interface to the mass storage client driver.
SCSI Command Support	usb_host_msd_scsi.c	Provides SCSI command support for a USB embedded host utilizing the mass storage client driver.
	usb_host_msd_scsi.h	Header file with definitions for USB embedded hosts using the mass storage client driver and SCSI commands. This file also includes definitions to link the AN1045 function name requirements to this implementation.
File System Support (installed as a part of AN1045)	FSIO.c	Provides simple commands to perform file activities, such as open a file, read from a file, write to a file, close a file, etc.
	FSIO.h	Header file with prototypes for the file system functions.
	FSDefs.h	Header file with constants and data structures required by the file system functions.
Application	uart2.c	Provides an interface to UART2 to provide RS-232 input and output to the application.
	uart2.h	Header file for the UART2 functions.
	FSConfig.h	Configures the file system library for this application.
	usb_config.c	Configures the USB Stack for this application. Generated by the configuration tool.
	usb_config.h	Configures the USB Stack for this application. Generated by the configuration tool.
	system.h	Contains system level constants for libraries to reference.
	usb_data_logger.c	Main application code.

TABLE 2: FILE SYSTEM INTERFACE FUNCTIONS

Library Function Name	Description	Data Logger Implementation Name
InitIO()	Called when a device is connected.	USBHostMSDSCSIInit()
MediaDetect()	Indicates whether or not media is currently attached.	USBHostMSDSCSIMediaDetect()
SectorRead()	Reads the indicated sector.	USBHostMSDSCSISectorRead()
SectorWrite()	Writes the indicated sector.	USBHostMSDSCSISectorWrite()
WriteProtectState()	Indicates if the media is write-protected	USBHostMSDSCSIWriteProtectState()

Application Functionality

The data logger application consists of three main components:

- File Manipulation Capability
- Command Interface
- Data Logging

FILE MANIPULATION CAPABILITY

By utilizing the file system library described in AN1045, this application provides simple, but powerful, file manipulation capabilities:

- Viewing files in the current directory
- Creating and removing directories
- Changing the current directory
- Copying files and sending files to the UART
- Creating files from the command line
- Deleting files

Note:	File specification limitations on these commands, such as wild cards and directory specification, are determined by the file system library implementation. If the file system library is updated, these limitations may change.

COMMAND INTERFACE

The user interfaces with the application by connecting the Explorer 16 Board's DB9 serial connector to a PC running a terminal emulation program, such as HyperTerminal. The terminal emulation program should be set to 57600 baud, 8 data bits, no parity, 1 Stop bit and no flow control. Upon initialization, a banner is displayed, follow by a command prompt:

```
***** Microchip Explorer vx.yy.zz *****

>
```

The user may enter commands at the command prompt. All command entries are converted to upper case. The user may edit the command as it is being entered by using the Back Space key. Arrow key editing (left and right arrows) is not supported.

The application also has a configurable buffer of previous commands. The user may display and scroll through these commands by using the up arrow and down arrow keys. The user may edit the displayed command by using the Back Space key. Arrow key editing (left and right arrows) of these commands is not supported.

When the user presses the Enter key, the application performs the indicated command.

The command prompt when no Flash drive is inserted is simply "`>`". When a Flash drive is inserted, the drive's volume label is read and incorporated into the command prompt. For example, if a Flash drive with the volume label "FLASH" is inserted, the command prompt will be displayed as "`FLASH:\>`".

A complete list of file system commands and their syntax is provided in Table 3. A brief description of the file system library functions required to implement the file manipulation commands follows.

`CD` (Change Directory)

`FSchdir()` changes the current directory.

`COPY` (Copy File)

If a source file is specified, this command utilizes the function, `FindFirst()`, to locate the file. `FSfopen()` opens the source and destination files. `FSfread()` reads from the source file, and `FSfwrite()` writes to the destination file until `FSfeof()` indicates the end of the source file. `FSfclose()` then closes the source and destination files.

`DEL` (Delete File)

`FindFirst()` locates the file to delete. If the file is found, `FSremove()` deletes it.

`DIR` (Display File Directory)

`FindFirst()` locates the first file in the directory and returns information about the file. Then, `FindNext()` locates and returns information about additional files in the directory.

`MD` (Make Directory)

`FSmkdir()` creates a directory with the given name.

`RD` (Remove Directory)

`FSrmdir()` removes the directory with the given name.

`TYPE` (Display File)

`FindFirst()` locates the specified file. `FSfopen()` then opens the file. The file contents are read using `FSfread()` until `FSfeof()` indicates the end of the file. `FSfclose()` then closes the file.

TABLE 3: SUPPORTED FILE SYSTEM COMMANDS

Command Syntax	Description	Requirements	Example
CD <name>	Change current working directory	At least one space must be entered after “CD”.	CD .. CD \ CD NEXT CD NEXT\ONE
COPY <file1> <file2>	Copy [file1] to [file2]		COPY A.TXT B.TXT
COPY CON <file>	Create [file] from console input	User entry while creating the file is not converted to upper case. Characters are echoed as they are entered. No editing is allowed; characters are written to the file immediately. Entry is terminated by entering <Ctrl-Z>.	COPY CON USER.TXT
DATE [yyyy-mm-dd]	Display or set the date	All required digits must be specified.	DATE DATE 2007-06-22
DEL <file>	Delete file	The file must be in the current working directory.	DEL FILE.TMP
DIR [file]	Display directory	Displays file name, date/time-stamps and size. Indicates directories.	DIR DIR *.TXT
HELP | ?	Display help		HELP ?
LOG <POT|TMP> <file>	Log ADC input to file	See the sections on data logging that follow. Logging is terminated by entering <Ctrl-C>.	LOG POT P.CSV LOG TMP T.CSV
MD <name>	Make directory		MD NEWDIR
RD <name>	Remove directory		RD NEWDIR
RESET <SOFT|HARD>	For development purposes. SOFT performs a mass storage Reset; HARD performs a USB Reset.	Intended for development purposes.	RESET HARD
TIME [hh:mm:ss]	Display or set the time	Time is displayed and entered in 24-hour format. All required digits must be specified.	TIME TIME 19:30:00
TYPE <file>	Sends the contents of the file to the terminal window	<file> must be in the current working directory. Not recommended for binary files.	TYPE P1.CSV

LOW DATA RATE DATA LOGGING

Many applications need to monitor and record data with a time-stamp of when the data sample was obtained. For data that is monitored on a time scale of seconds, minutes or hours, the Real-Time Clock and Calendar (RTCC) provides a simple, useful method of time-stamping the data. The `DATE` and `TIME` commands are provided in the command interface to easily set and display the current date and time of the RTCC.

The `LOG` command can then be used to perform low data rate, real-time monitoring of the voltage across the potentiometer on the Explorer 16 Demo Board. When the user enters the command, `LOG POT <file>`, the application monitors the RTCC to determine when one second has elapsed. Every time one second passes, the application performs an analog-to-digital conversion on the potentiometer, which is connected to AN5. The time-stamps and potentiometer readings are formatted into a text string and stored in a buffer that matches the size of one media sector. When the buffer is full, the buffer is written to the Flash drive using the file name given on the command line.

The Comma Separated Value (.csv) format of the text string was chosen for ease of import into a spreadsheet program, such as Microsoft® Excel. It can easily be modified for import into a custom application.

EXAMPLE 1: SAMPLE DATA, POTENTIOMETER MONITOR

```
2007-08-15,04:29:18,00868
2007-08-15,04:29:19,00869
2007-08-15,04:29:20,00869
```

Implementation Details

The file system command, `FSfopen()`, opens the specified file for writing. Then, the application configures the ADC to manually sample AN5, as shown in Example 2.

EXAMPLE 2: A/D CONFIGURATION FOR POTENTIOMETER MONITOR

```
AD1CON2 = 0;      //AVdd, AVss, MUXA only
AD1CON3 = 0x0005; //No auto-sample time,
                  //Tad = 5*Tcy
AD1CHS  = 0x5;    //MUXA uses AN5
AD1PCFG = 0;      //Disable digital input
                  //on AN5
AD1CSSL = 0;      //No scanned inputs
AD1CON1 = 0x8000; //Turn on, manual sample
                  //and conversion
```

The application determines when one second has elapsed by reading the current time of the RTCC and comparing it to the previously read time.

The application uses the library function, `sprintf()`, to place a formatted string containing the time-stamp and the ADC reading in a buffer. The application double-buffers the data to allow data to be read and written simultaneously. When a buffer is full, `FSfwrite()` writes the buffer to the Flash drive. `FSfclose()` closes the file when the user terminates logging.

HIGH DATA RATE DATA LOGGING

Most real-time data analysis requires that data be captured at a fixed, high-speed rate, on the order of milliseconds rather than seconds. While PCs offer great data analysis tools, they cannot be relied upon for real-time monitoring, since most operating systems cannot guarantee a fixed, precise time base. Small embedded applications can easily be created to monitor data at a fixed, high-speed rate, but they are not good platforms for performing data analysis. The high-speed data logging example demonstrates how to easily utilize the best features of both platforms by having the embedded application store the obtained data to a USB Flash drive.

The `LOG` command can be used to perform high-speed, real-time data monitoring of the temperature sensor on the Explorer 16 Demo Board. When the user enters the command, `LOG TMP <file>`, Timer3 is used to trigger an analog-to-digital conversion on AN4 every 10 ms. When the conversion completes, an interrupt fires, triggering a routine to format the temperature reading and time-stamp and store the resulting text string in a buffer that matches the size of one media sector. When the buffer is full, the buffer is written to the Flash drive using the file name given on the command line.

The Comma Separated Value (.csv) format of the text string was chosen for ease of import into a spreadsheet program. It can easily be modified for import into a custom application.

EXAMPLE 3: SAMPLE DATA, TEMPERATURE MONITOR

```
0000000010,00139
0000000020,00131
0000000030,00124
```

> **Note:** The time-stamp, which is the elapsed number of milliseconds shown in the first column, is included in this example for readability. For increased monitoring speed, the time-stamp can be eliminated from the output, since the interval between samples is known.

Implementation Details

The file system command, FSfopen(), opens the specified file for writing. Then, the application configures the ADC to sample AN4 when Timer3 rolls over, as shown in Example 4.

EXAMPLE 4: A/D CONFIGURATION FOR TEMPERATURE MONITOR

```
AD1CON2 = 0;      //AVdd, AVss, MUXA only
AD1CON3 = 0x1F05; //31 Tad auto-sample,
                  //Tad = 5*Tcy
AD1CHS  = 0x4;    //MUXA uses AN4
AD1PCFG = 0;      //Disable digital input
                  //on AN4
AD1CSSL = 0;      //No scanned inputs
AD1CON1 = 0x8046; //Turn on, start sampling,
                  //convert on Timer 3
```

Timer3 provides a tick count that is incremented with every rollover. The application is manually configured using the labels, MILLISECONDS_PER_TICK, TIMER_PRESCALER and TIMER_PERIOD, such that each tick is 10 ms. These labels are located in the file, system.h.

Upon the Timer3 rollover, the ADC automatically begins a conversion on AN4. When the conversion completes, the ADC interrupt fires.

The application uses the library function, sprintf(), to place a formatted string containing the time-stamp and the ADC reading in a buffer. The application double-buffers the data to allow data to be read and written simultaneously. When a buffer is full, FSfwrite() writes the buffer to the Flash drive. FSfclose() closes the file when the user terminates logging.

THE USB CONFIGURATION TOOL

The USB data logger application has already been configured by using the graphic USB configuration tool, USBConfig.exe, located in the installation directory, \Microchip\USB. The configuration files, USBConfig.c and USBConfig.h, were generated and stored in the .\USB Data Logger project directory.

The following configuration options have been selected:

1. At the Main tab (Figure 3):
   a) Device Type: “USB Embedded Host”
   b) Ping-Pong Mode: “All endpoints”
2. At the Host tab (Figure 4):
   a) Transfer Type: “Bulk Transfers” only, with 10,000 NAKs allowed (Control Transfers are also enabled, with dialog text appearing in grey)
   b) Attach Debounce Time: 250 ms
   c) Name of Application Event Handler: USB_ApplicationEventHandler

> **Note 1:** The Attach Debounce Time is increased from the USB specification minimum of 100 ms to allow for slower devices.
>
> **2:** To conserve program and data memory, transfer events are not used.
>
> **3:** The number of allowed NAKs may be adjusted if faster or slower Flash drives are used.

3. At the TPL (Targeted Peripheral List) tab (Figure 5):
   a) “Support via Class ID” is selected
   b) Client Driver: Mass Storage
   c) Class: Mass Storage (0x08)
   d) SubClass: SCSI Command Set (0x06)
   e) Protocol: Bulk-only Transport (0x50)
   f) Initial Configuration: 0
   g) Initialization Flags: 0
   h) HNP: Not Allowed

> **Note:** While these settings are intended for USB Flash drives, other mass storage devices (such as memory card readers) also use this interface, and will probably work with this demo application.

4. At the Mass Storage tab (Figure 6):
   a) “Mass Storage Is Used in Host Mode” is selected
   b) Under “Media Interface”, “SCSI Interface” is selected (the other fields are automatically populated, and are greyed out)

FIGURE 3: USB CONFIGURATION TOOL, MAIN TAB

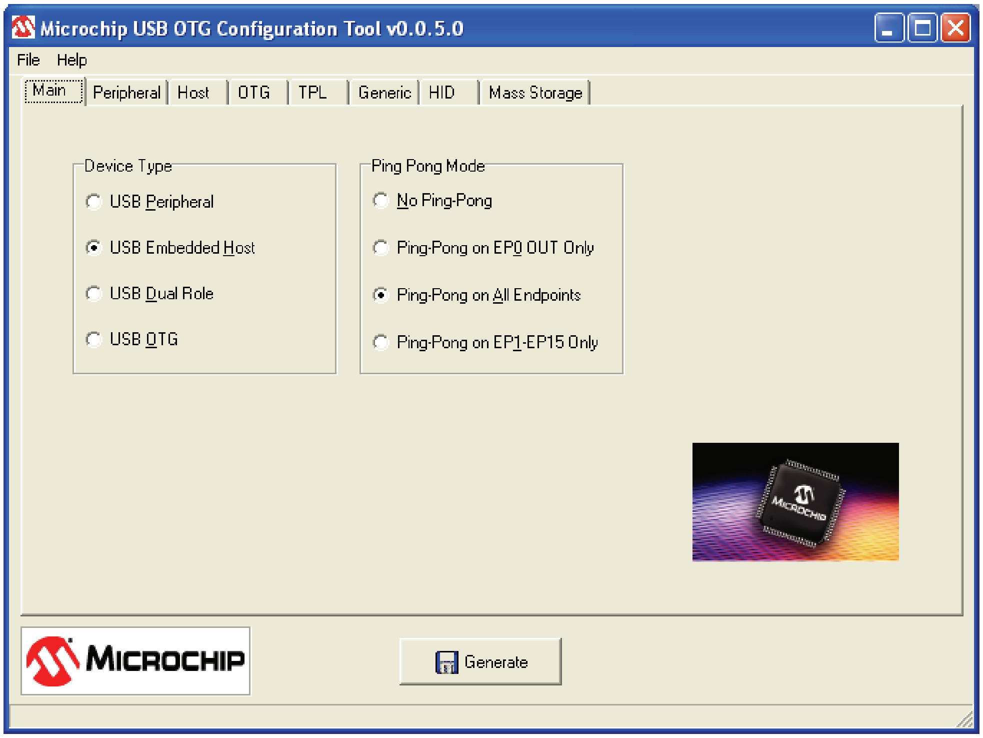


FIGURE 4: USB CONFIGURATION TOOL, HOST TAB

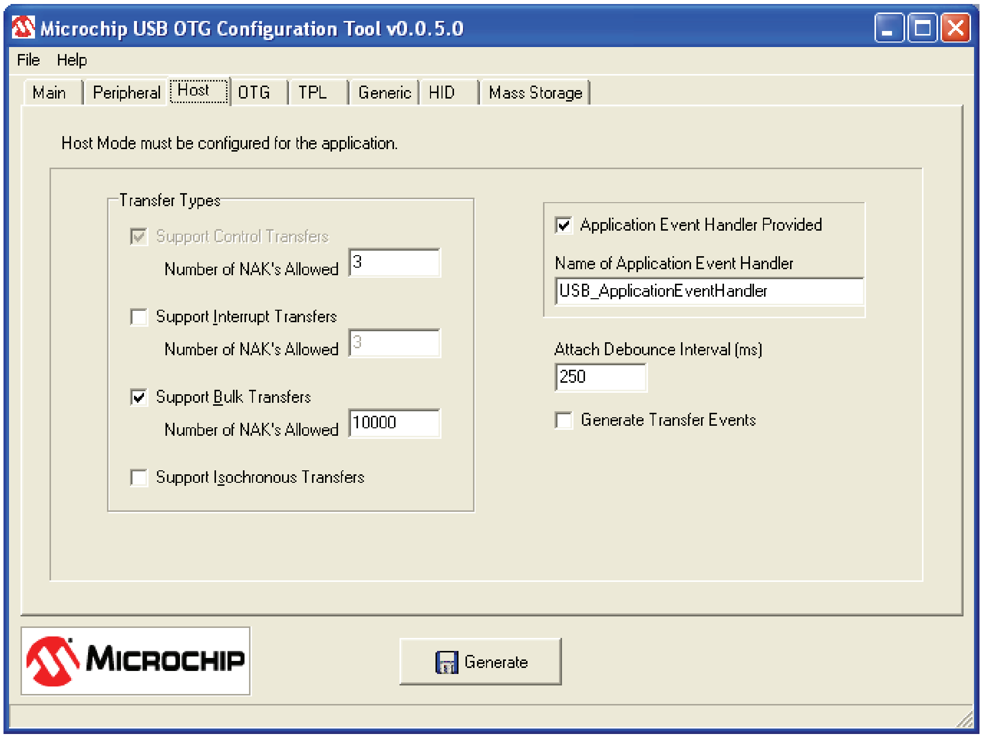


FIGURE 5: USB CONFIGURATION TOOL, TPL TAB

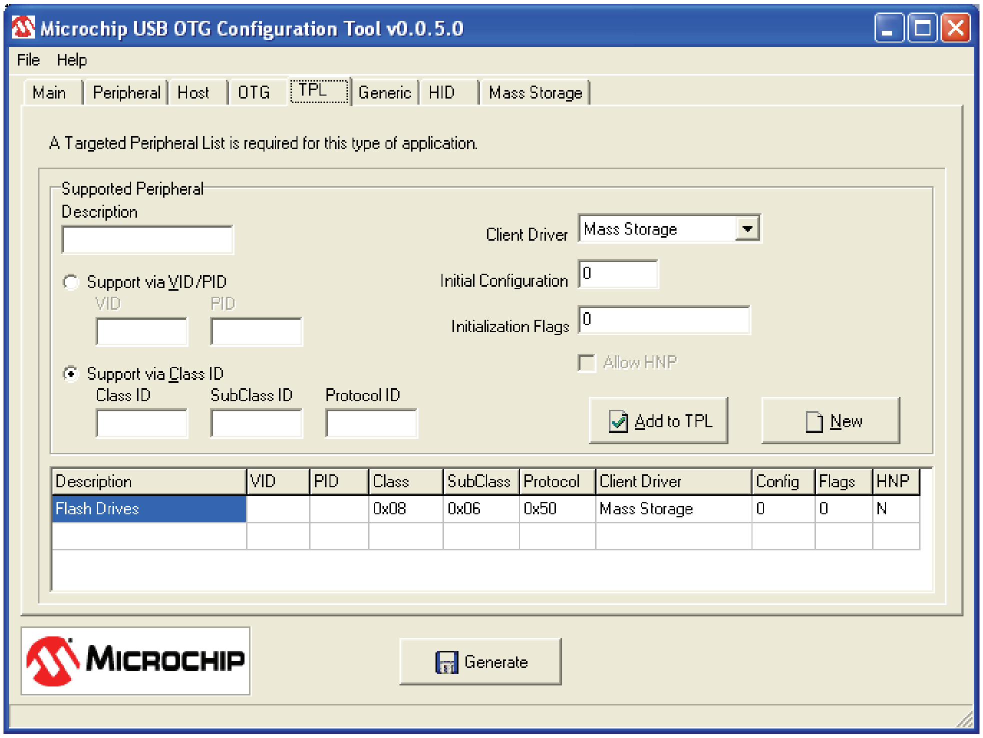
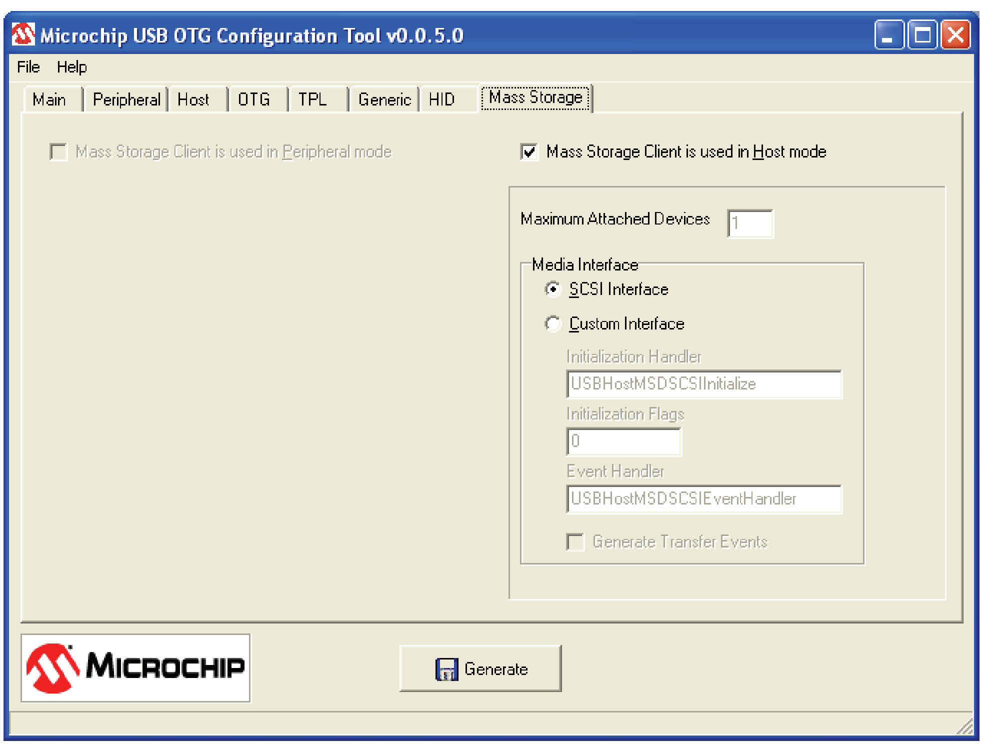


FIGURE 6: USB CONFIGURATION TOOL, MASS STORAGE TAB



CONCLUSION

Using Microchip's USB embedded host capability with the mass storage class client driver, embedded applications can now read from and write to USB mass storage devices, such as USB Flash drives. This capability gives embedded applications virtually unlimited data storage, providing simple, but powerful, connectivity between the embedded world and the realm of PCs.

REFERENCES

For more information on components of the Microchip USB Embedded Host 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 Application Note *AN1140, "USB Embedded Host Stack"* (DS01140)
- Microchip Application Note *AN1141, "USB Embedded Host Stack Programmer's Guide"* (DS01141)
- Microchip Application Note *AN1142, "USB Mass Storage Class on an Embedded Host"* (DS01142)

For more information on USB and embedded host functionality in general:

- USB Implementers Forum, *"Universal Serial Bus Revision 2.0 Specification"*, http://www.usb.org/developers/docs/
- USB Implementers Forum, *"Requirements and Recommendations for USB Products with Embedded Hosts and/or Multiple Receptacles"*, http://www.usb.org/developers/docs/

APPENDIX A: SOFTWARE DISCUSSED IN THIS APPLICATION NOTE

The USB data logger application is available for download as part of Microchip's USB Embedded Host Library. This software library, delivered as a WinZip archive, contains the source code and support files required for all layers of the application. Interested users may download the USB Embedded Host Library from the Microchip corporate web site, at

www.microchip.com/usb

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