INTRODUCTION

Most computer users are familiar with the numeric keypad section on a computer keyboard. The numeric keypad is generally used to enter long sequences of numbers, or while working with applications such as calculator, spreadsheet and accounting programs. However, most laptop manufacturers do not provide a numeric keypad section on their keyboard due to space constraint.

The Microchip USB keypad demo is an easy plug-and-play USB keypad which can be plugged into a computer or a USB host to make the numeric keypad available. The USB keypad is designed using the PIC16F1459 device, which is part of Microchip’s 8-bit USB-capable family, PIC16F14XX.

This application note describes the USB Keypad Reference Design. The PCB layout for the capacitive touch sensors arranged in a matrix is also provided.

Visit the Microchip web site for the following:

• For more information on Microchip’s capacitive sensing solutions, visit http://www.microchip.com/mTouch.
• For more information on Microchip’s USB solutions, visit http://www.microchip.com/USB.

DEMONSTRATION HIGHLIGHTS

All the USB keypad features are driven by a single device, PIC16F1459.

The following list describes the USB keypad features:

• Crystal-free USB operation
• 18 touch buttons using Microchip’s Capacitive Voltage Divider (CVD) technique
• LED backlight with proximity sensing ON and auto power OFF
• Audio feedback using piezo buzzer
• USB Human Interface Device (HID) interface
• Plug-and-play
• Low-cost light weight design

Figure 1 illustrates the USB keypad.

FIGURE 1: USB KEYPAD

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RUNNING THE USB KEYPAD DEMO

With the preinstalled demo application, the PIC16F1459 USB keypad is designed to be used straight out of the box. Except for a single connection to a computer, no additional hardware or configuration is necessary. Connect the provided USB cable (A- to mini-B) to any available USB port on the PC or powered hub, and then connect to the USB keypad at the mini-B receptacle on the bottom side of the board. The PC USB connection provides communication and power to the USB keypad. The USB keypad is ready for operation once it is connected to the PC through the USB.

Initially, when the USB keypad is plugged into a USB host, the LED backlight is turned ON and the USB keypad is ready for operation. Touch any button on the keypad to send the corresponding character to the host. The buzzer beeps for every recognized key touch. The beep frequency is set to 1 kHz when Num Lock is ON and 2.5 kHz when Num Lock is OFF. Num Lock ON and OFF operations produce a slightly longer beep. To disable the buzzer beep, press and hold the Clear button for two seconds or until a longer beep is heard from the buzzer. Touch and hold the Clear button again to turn on the buzzer feedback.

The LED backlight is turned off automatically if no activity is detected on the keypad for more than seven seconds. When LED backlight is off, the keypad is inactive. At this time, the proximity sensors regularly scan for any object (for example, a finger or any other object which causes a change in capacitance) near the vicinity (2 cm to 3 cm) and turns on the LED backlight if any object is detected.

The USB keypad consumes around 250 mA when the LED backlight is ON. Therefore, ensure that the USB host is capable of delivering this current to the device. A USB host might reject the USB keypad configuration if it is unable to deliver the current requested by the keypad.
USB KEYPAD HARDWARE LAYOUT

The USB keypad hardware layout and its components are illustrated in Figure 2 and Figure 3.

FIGURE 2: USB KEYPAD PCB BOTTOM SIDE

- PIC16F1459 MCU (U1): SSOP package
- Six-pin (J2), right-angle In-Circuit Serial Programming™ (ICSP™) programmer/debug header package
- Mini-B USB connector (J1) for power and communication
- External drive buzzer (B1) for audio feedback
- IRLML6246: MOSFET (Q1)

FIGURE 3: USB KEYPAD PCB TOP SIDE

- Capacitive touch sensors (S1 to S18)
- Guard ring for shielding the touch sensors from parasitic capacitance
- IBC-2810UWC: LEDs for backlighting (D1 to D12)
USB KEYPAD BLOCK DIAGRAM

The USB keypad features are driven by an 8-bit PIC16F1459 device with integrated peripherals such as 14 KB Flash, 1 KB RAM, full-speed USB peripheral with Active Clock Tuning (ACT), 10-bit Analog-to-Digital Converter (ADC) with nine channels, two Pulse-Width Modulator (PWM) modules, Complementary Waveform Generator (CWG), and so on.

Figure 4 illustrates the USB keypad block diagram.

FIGURE 4: USB KEYPAD BLOCK DIAGRAM

9 CVD sensors are arranged in a 5 x 4 matrix for a maximum of 20 touch buttons on the keypad. This keypad has 18 touch buttons. The columns sensors are also used for proximity sensing.

The Active Clock Tuning module continuously adjusts the 16 MHz internal oscillator on every SCIF signal from the USB host. This eliminates the need for a high-speed, high-accuracy external crystal which is otherwise required for USB full speed operation.

PWM2 generates square waves to drive the piezo buzzer. The CWG (Complementary Waveform Generator) module is used to route the signal to another pin.

12 LEDs provide backlighting for the front panel from both sides.

USB Mini B Connector
+5V
Data (−)
Data (+)
Capacitive Touch Buttons

The Capacitive Voltage Divider (CVD) technique is used for implementing 18 touch buttons and the proximity sensor. The CVD technique has been developed to require only an ADC and minimal digital processing overhead. For more information on the CVD technique, refer to “mTouch™ Sensing Solution Acquisition Methods Capacitive Voltage Divider” (AN1478), or visit the Microchip web site at: http://www.microchip.com/mtouch.

All of the nine ADC channels available on the PIC16F1459 device are configured as CVD sensors. To allow a larger number of touch buttons, nine CVD sensors are arranged in a 5 x 4 matrix (see Figure 5). The 5 x 4 matrix allows a maximum of 20 touch buttons. However, the USB keypad implements 18 touch buttons.

Each touch button includes a pair of row and column. The rows and columns in a touch button are separated by a distance of 1.5 mm. Most of the touch buttons on the USB keypad have an overall size of 12 mm x 12 mm. There are two touch buttons with a size of 12 mm x 31 mm.

Figure 6 illustrates the dimensions for an individual button. The CVD firmware finds out if any touch button is pressed by scanning all of the nine sensors at a periodic interval, and by checking if any combination of row and column is pressed.

FIGURE 5: MATRIX KEYPAD DESIGN

FIGURE 6: TOUCH BUTTON DIMENSIONS

All of the four column sensors are also used for proximity sensing. The CVD firmware scans these four column sensors separately to find out if any change in the capacitance is detected due to the presence of an object (human interference).

Each touch button is surrounded by a guard ring to shield the buttons from parasitic capacitance, thus increasing the sensitivity of the button. The guard ring is driven by an I/O. The guard ring has a width of 1 mm, and is placed at a distance of 3 mm from the touch buttons.
Full-Speed USB with Active Clock Tuning

The USB keypad is a full-speed USB device which enumerates as HID keyboard to a USB host. The USB HID driver is built in most operating systems such as Windows, Linux, Mac, and so on. The device drivers are installed automatically on these operating systems as the user plugs in the keypad to the USB connector on the host.

The PIC16F1459 device contains a full-speed (12 Mb/s) and low-speed (1.5 Mb/s) compatible USB Serial Interface Engine (SIE) that allows fast communication between any USB host and the MCU. The SIE can be interfaced directly to the USB by utilizing the internal transceiver.

USB standards specify that Full Speed USB clock tolerance should be within +/- 0.25%. Most USB systems achieve this requirement by using an external crystal. However, the PIC16F1459 device consists of the Active Clock Tuning (ACT) feature, which eliminates the need for a high-speed, high accuracy external crystal in a full-speed USB system. The ACT continuously adjusts the 16 MHz internal oscillator using an available external reference, to achieve ± 0.20% accuracy. In a full-speed USB system, the Start-of-Frame (SOF) signal received every millisecond from a USB host can be used as the external reference. The ACT feature helps save BOM and assembly costs on the external crystal and also saves some board space.

LED Backlight

Backlighting of the USB keypad is done using 12 side-firing LEDs soldered on the top layer of the PCB. Six LEDs each are soldered on both the left and right sides of the PCB. The LEDs are arranged on the PCB in a way to ensure proper lighting of the touch buttons.

LEDs are driven using the PWM peripheral on the PIC16F1459 through a MOSFET IRLML 6246. LEDs are turned ON when the proximity sensors detect an object (for example, a finger or any other object which causes a change in capacitance) near to it (or there is a change in sensor capacitance). LEDs are turned OFF automatically after 5-7 seconds.

In order to spread the LED backlight throughout the panel properly, LEDs are physically placed close to the slot provided on the front panel. Proper LED soldering pads (see Figure 7) on the PCB are used.

Buzzer

An external drive buzzer is provided to generate an audio tone whenever a key is pressed. The audio feedback helps the user to realize that a button is pressed. The buzzer is connected to the PIC16F1459 through the PWM2 peripheral. The PWM2 peripheral generates rectangular waves to drive the buzzer. The tone frequency is changed by varying the PWM period. The buzzer volume can be adjusted by varying the PWM duty cycle.

The dedicated PWM2 pin PIC16F1459 MCU is also an ADC channel (AN8). AN8 channel is used as a capacitive sensor and hence is not available for connecting the buzzer. Therefore, the output of the PWM2 to RC4 pin is rerouted internally using the Complimentary Waveform Generator (CWG) peripheral.

Figure 7 illustrates the LED solder pad dimensions on the PCB.
Front Panel

The front panel is fixed on top of the USB keypad PCB. The graphics for the USB keypad is printed on the front panel which also has slots for holding the LEDs. The front panel guides the LED backlight and helps to illuminate the buttons. The front panel is self adhesive and can be pasted on the keypad PCB. The front panel is manufactured by Lumvatech, LLC.

Figure 8 illustrates the dimension details of the front panel. The LED slots are placed such that the backlight is spread equally throughout the panel.

FIGURE 8: LED PLACEMENT ON PCB (LED PLACEMENT IMAGE)
**FIRMWARE**

The two major components of USB keypad firmware are: USB device stack and mTouch™ CVD library. Both of these components are taken from the Microchip Libraries for Application (MLA) without any modifications.

Figure 9 illustrates the high-level software architecture.

The USB keypad application scans all the mTouch proximity sensors and buttons at a regular interval set by a timer. The USB keypad is activated only when the proximity sensor detects a change in capacitance value due to an object (for example, a finger) in the near vicinity. The USB keypad application polls every button at a regular interval, and sends the specific character of the button to the USB host. See Figure A-1 for the application flowchart.

**Folder Structure**

Figure 10 illustrates the USB keypad firmware folder structure. The application folder contains the MPLAB® X project, application source files, USB stack configuration files, hardware profile files, and so on.

The Microchip core stack files folder contains the USB device stack and mTouch CVD framework files. These files are copied without any modifications from the MLA. If a new version of the USB device stack or mTouch CVD framework is available, the contents inside the Microchip core stack files folder can be replaced with the new files copied from the MLA.
Demo Configuration

Some of the features of the demo can be changed by modifying the macro defined in the Keypad_Configuration.h file.

Example 1 provides the configuration details of the USB keypad.

EXAMPLE 1:  USB KEYPAD CONFIGURATION DETAILS

```c
//The KEYPAD_TIMEOUT macro defines how long the Keypad should active after // the last user activity.
#define KEYPAD_TIMEOUT 7000 //milli Seconds
#define LED_BACKLIGHT_ENABLE //Define to enable LED backlight
#define BUZZER_ENABLE // define to enable buzzer
#define ENABLE_BUZZER_ON_OFF_USING_CLEAR_BUTTON // define to enable/disable buzzer using 'Clear' Button
```

FIGURE 11: MEMORY USAGE

<table>
<thead>
<tr>
<th>RAM Usage</th>
<th>388 Bytes of 1024 Bytes</th>
<th>38%</th>
</tr>
</thead>
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<tr>
<td>mTouch Framework</td>
<td>274 Bytes</td>
<td></td>
</tr>
<tr>
<td>USB stack</td>
<td>76 Bytes</td>
<td></td>
</tr>
<tr>
<td>Application</td>
<td>38 Bytes</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Program Memory Usage</th>
<th>6383 Words of 8192 Words</th>
<th>78%</th>
</tr>
</thead>
<tbody>
<tr>
<td>mTouch Framework</td>
<td>3000 Words</td>
<td></td>
</tr>
<tr>
<td>USB Stack</td>
<td>1800 Words</td>
<td></td>
</tr>
<tr>
<td>Application</td>
<td>1563 Words</td>
<td></td>
</tr>
</tbody>
</table>

Debugging the Code

In the PIC16F1459 device, the ICSPCLK and ICSPDAT (ICSP™ and debug pins) pins are multiplexed with ADC input AN4 and AN5. The USB keypad uses AN4 and AN5 as CVD sensors. Hence, it is not possible to run the code in Debug mode because the debug pins are used as CVD sensors. In order to debug the code, R32 and R33 0Ω resistors (see Figure 2) should be opened by desoldering.

Observing CVD Sensor Values on PC

The CVD values for each sensor on the keypad (including the proximity sensors) can be watched on a PC terminal program (for example, HyperTerminal). Follow the below steps for observing the CVD values:

1. Open the USB keypad firmware project on MPLAB X.
2. In the mComm_config.h file, uncomment the following line:
   ```c
   #define MCOMM_ENABLED
   ```
3. In the usb_config.h file, select the USB polling method as shown below:
   ```c
   #define USB_POLLING
   //define USB_INTERRUPT
   ```
4. Using MPLAB X, build and program the firmware on to the board.
5. Connect the test point TP2 (RB6 of the PIC16F1459) to the RX pin of the PC through a USB to serial converter.
6. Open a HyperTerminal or any other similar application, with a baud rate setting of 38400 bps.
7. Plug the USB keypad to the PC USB port. The HyperTerminal displays the CVD values for each CVD sensor.
CONCLUSION
The USB keypad implements 18 touch buttons, proximity sensing, full-speed USB without crystal, LED backlighting using PWM, and external drive buzzer using PWM. All of the features are driven by a single PIC16F1459 MCU which result in low bill of materials (BOM) cost. The USB keypad demo also showcases many features that are common/useful to many other applications with USB and capacitive touch sensors.

REFERENCES
The following resources can be downloaded from the Microchip web site:
- “mTouch™ Sensing Solution Acquisition Methods Capacitive Voltage Divider” (AN1478)
- USB keypad demo, documentation and C source code can be modified as per user specific application requirements:
  www.microchip.com/USBKeypad
- Touch Sense Solutions:
  www.microchip.com/mTouch
- USB Solutions:
  www.microchip.com/USB
- Microchip MLA:
  www.microchip.com/MLA
APPENDIX A: APPLICATION FLOWCHART

Figure A-1 illustrates the USB keypad application flowchart. The keypad.c file contains the main application.

FIGURE A-1: APPLICATION FLOW CHART
Figure B-1 illustrates the USB keypad schematic.

FIGURE B-1: SCHEMATIC

[Diagram of the USB keypad schematic]
APPENDIX C: USB KEYPAD: BILL OF MATERIALS

Table 1 provides the Bill of Materials (BOM) for USB keypad.

<table>
<thead>
<tr>
<th>Device Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>PIC16F1459: SSOP package</td>
</tr>
<tr>
<td>D1-D12</td>
<td>IBC-2810UWC: Side firing LED</td>
</tr>
<tr>
<td>R1, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13, R14, R15, R16, R17</td>
<td>Resistor: 100Ω, 1/10W, 1% 0603 SMD</td>
</tr>
<tr>
<td>R2, R31</td>
<td>Resistor: 1.00 kΩ, 1/10W, 1% 0603 SMD</td>
</tr>
<tr>
<td>R3, R19</td>
<td>Resistor: 10.0 kΩ, 1/10W, 1% 0603 SMD</td>
</tr>
<tr>
<td>R18</td>
<td>Resistor: 22.0 kΩ, 1/10W, 1% 0603 SMD</td>
</tr>
<tr>
<td>R20, R21, R22, R23, R24, R25, R26, R27, R28</td>
<td>Resistor: 4.70 kΩ, 1/10W, 1% 0603 SMD</td>
</tr>
<tr>
<td>R29</td>
<td>Resistor: 100 kΩ, 1/10W, 1% 0603 SMD</td>
</tr>
<tr>
<td>R30</td>
<td>Resistor: 1.00 MΩ, 1/10W, 1% 0603 SMD</td>
</tr>
<tr>
<td>R32, R33</td>
<td>Resistor: 0Ω, 1/10W, Jumper, 0603 SMD</td>
</tr>
<tr>
<td>C1</td>
<td>Capacitor Ceramic: 1 μF 50V 10% X5R 0603</td>
</tr>
<tr>
<td>C2</td>
<td>Capacitor Ceramic: 0.47 μF 16V 10% X7R 0805</td>
</tr>
<tr>
<td>C3, C4</td>
<td>Capacitor Ceramic: 0.1 μF 25V 10% X7R 0603</td>
</tr>
<tr>
<td>C5</td>
<td>Capacitor Ceramic: 10000 pF 25V 10% X7R 0603</td>
</tr>
<tr>
<td>C6</td>
<td>Capacitor Ceramic: 1000 pF 16V 10% X7R 0603</td>
</tr>
<tr>
<td>L1</td>
<td>Ferrite Bead: 33Ω 0603</td>
</tr>
<tr>
<td>Q1</td>
<td>IRLML6246 MOSFET: N channel 20V 4.1A SOT-23</td>
</tr>
<tr>
<td>J1</td>
<td>Connector Receptacle: Mini-B USB 2.0, 5 positions</td>
</tr>
<tr>
<td>J2</td>
<td>Connector Header: 100 RT/A SMD, 6 positions</td>
</tr>
<tr>
<td>D13</td>
<td>Diode Standard Receptacle: 1A, 300V and SMA</td>
</tr>
<tr>
<td>B1</td>
<td>Piezo Buzzer: 25VP-P SMD PKLC51212E4001-R1</td>
</tr>
<tr>
<td>Bump on</td>
<td>Bumpon X – Tall Taper SQ.81X.30BK</td>
</tr>
</tbody>
</table>
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