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Low-Power Capacitive Sensing with the Capacitive Sensing Module

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INTRODUCTION

This technical brief describes a small application that demonstrates the low-power capacitive touch potential of the Capacitive Sensing Module (CSM). The main benefit of this new part is the introduction of a special module for capacitive sensing detection. A more detailed description about this module can be found in AN1171, *"Using the Capacitive Sensing Module on the PIC16F72X"*.

HARDWARE DESCRIPTION

A simple design was developed to create a board using the PIC16F726 (the first family to integrate the Capacitive Sensing Module), a simple LED driver IC Allegro 6276 and 16 surface-mounted LEDs, arranged in a 4x4 matrix. The LED driver was introduced in order to separate the current path of the LEDs from that of the microcontroller, hence a more accurate current consumption measurement on the device's side. The inputs to the CSM are represented by 8 capacitive pads. The V_{DD} line of the microcontroller is shunted by a small 100 Ohms resistor for measuring the current consumption by the device. The board schematics can be found in **Appendix A: Low-Power Capacitive Touch – PIC16F726**.

The purpose of the board is to allow the user to move a row of 3 LEDs in the matrix using the arrow buttons, reset their position and vary the frequency at which these LEDs are lit using the slider keys positioned on the right side of the board.

The frequency measurement for each button consists of Timer1 acting as a counter and WDT acting as a time base. The counter will increment itself on every rising edge coming from the Capacitive Sensing Module. The time base represents the acquisition window for these pulses. Furthermore, the time base, in this case the WDT overflow, will determine the start and stop of the counter.

The combination between the Capacitive Sensing Module and Timer1 leads to a normal decision to use the Toggle mode of the Timer1 gate. This means that, on the first overflow of the WDT, the counting mechanism of Timer1 will be enabled and, on the next WDT overflow, the same mechanism will be disabled, but an interrupt will be generated by the Timer1 gate. This interrupt shows that a gate event has taken place.

Table 1 provides a short description of the capacitive buttons.

TABLE 1: DESCRIPTION OF THE CAPACITIVE BUTTONS

Button Name	Description
WAKE-UP	Scanned for detection of the user's hand in proximity of the board.
RIGHT	Scanned for the detection of the user's intention to shift one position to the right of the row of LEDs.
LEFT	Scanned for the detection of the user's intention to shift one position to the left of the row of LEDs.
UP	Scanned for the detection of the user's intention to shift one position up the row of LEDs.
DOWN	Scanned for the detection of the user's intention to shift one position down the row of LEDs
RESET	Scanned for the detection of the user's intention to reset the row of lit LEDs to its default value.
SLIDER	This is a mixed button formed of two independent buttons connected in anti-phase. It is scanned to detect the user's intention to modify the frequency at which the LEDs are lit, from a relative low frequency to an ultra-low frequency. This limitation is caused by the fact that the time base is around 70 ms (WDT overflowing twice with the prescaler bits cleared).

The microcontroller scans only one key, trying to detect a shift in capacitance of the WAKE-UP button. This procedure acts as a proximity detector. When such a proximity event takes place, the microcontroller will scan all the buttons to detect the user's will to play with the LEDs in the matrix.

SOFTWARE DESCRIPTION

The PIC16F726 CSM allows the user to select between three time bases for the frequency measurement. Because the idea behind this small application was to do the detection while in Sleep mode, WDT was selected to create the time window. The firmware flowchart is shown in **Appendix B: Firmware Flowchart**.

The code begins with the initialization of the microcontroller. The only peripherals needed for the low-power capacity sensing are Timer1, WDT and the CSM. All other peripherals must be inactive, with the corresponding interrupt enable bits disabled. There are some peripheral interrupt events that can wake the device from Sleep and disrupt the WDT time window, because the WDT is cleared upon such an event, no matter its source. The user should avoid setting any peripheral interrupt enable bit other than TMR1 Gate Interrupt Enable bit (TMR1GIE), Peripheral Interrupt Enable bit (PEIE) and Global Interrupt Enable bit (GIE). The only special microcontroller feature needed in this kind of application is the precision internal oscillator which can be accessed via the OSCCON register. A convenient internal clock source can be obtained by enabling the PLL and selecting a frequency of 2 MHz or by having the PLL disabled and selecting a frequency of 500 kHz. The difference between the two frequencies is that the first one is higher and will allow the device to execute the code faster when awake, but will draw more current due to the enabled PLL; while the second one will trigger the device to execute the same code slower, but with a lower current consumption. The average current drawn by the device using either of the two frequencies is the same.

After the device is initialized, it is put to Sleep until the first WDT overflow. On the first overflow there will be no trigger of the Interrupt Service Routine (ISR), because there hasn't been any Timer1 gate event. However, the second WDT overflow will determine the microcontroller to start executing the code from the ISR.

The algorithm used allows the microcontroller to scan for a single key only, thus detecting the proximity of the user's hand to the board. This reason, plus the fact that the device has to consume as little current as possible, leads to the configuration of the WDT prescaler in a 1:8 rate. This means that, if the time window created by the WDT overflowing twice measures approximately 70 ms, using the prescaler select bits will increase this window to approximately 560 ms.

The user can play with the prescaler rate select bits, PS<2:0>, in the OPTION register, to increase the time taken by the WDT timer to overflow, hence a longer period spent by the device in Sleep mode. On the other hand, the accuracy of capacitance shift detection must be taken into consideration, and so the WDT overflow period cannot be extended over a limit that no longer allows an acceptable scan rate of the buttons.

Consequently, until there is a proximity detection, the microcontroller will execute the detection algorithm of a single key, the WAKE-UP button, once every ~560 ms. If a proximity detection has been performed, the microcontroller will clear the prescaler selection bits, and thus scanning every ~70 ms. This means that the user's hand is in close proximity to the board. The firmware detects it and allows all the keys to be scanned.

Once the user's hand is detected close to the board, the last state, or the default state of the LEDs will be flashed for a couple of seconds. This is an indication of the fact that the average values of the frequency readings of the buttons are revalued. Once this process is finished, the display will show the last state of the LEDs, or the default state – if this is the first proximity detection.

After 4 seconds of inactivity, the MCU shifts back the prescaler ratio and goes back to scan only one key. Thus, the user has about four seconds at his disposal to start playing with the keyboard, otherwise a time out is considered.

Pressing the WAKE-UP button again during this time interval of four seconds has no effect. Only when this interval expires and the microcontroller starts scanning again just this button, at a much slower rate, can a proximity detection be performed again for the WAKE-UP button.

The buttons are considered *press and release*, meaning that only the release of a button will generate an action. The only exception is the WAKE-UP button, which is scanned at a more sensitive threshold for detecting proximity.

CURRENT MEASUREMENT

A brief look at the schematic in **Appendix A: Low-Power Capacitive Touch – PIC16F726** shows that the current consumption by the microcontroller can be measured via the shunt R1 resistor on the V_{DD} line.

Because the voltage drop on the shunt resistor is a DC signal with a varying amplitude, the current resulted is not constant. Thus, we can have a couple of measurement techniques, which could be:

- the average DC voltage measurement of a TrueRMS multimeter
- plotting the voltage drop on a oscilloscope

Through the second choice, the user will detect the periodicity of the voltage drop pulses, calculate the duty cycle of the wave, measure the amplitude and then multiply the amplitude with the duty cycle. The result is the average voltage drop. Knowing the resistor's value, the current can be deducted. The voltage drop signal is an indication of the fact that the device wakes up from Sleep and executes the code.

Note that the voltage drop pulse width may vary in the periodicity window. Also, because the microcontroller wakes up to do the detection in two modes, once for the proximity detection and then for the whole keyboard detection, there are two calculations, both pursued in the same way, but with different data.

Here is an example:

TABLE 2:

Label	Definition
VDIFF	Voltage drop signal
Ton	VDIFF ON period
T	VDIFF period
VDIFF_AVG	Average value of VDIFF
VDIFF_AMPLITUDE	Amplitude of VDIFF
VDIFF_DC	Duty cycle of VDIFF

Let's presume that the VDIFF signal has a periodicity of five pulses. Four of them have a width of 2 ms, while the fifth has a width of 3.8 ms. Thus:

EQUATION 1:

$$Ton = 4*2ms + 3.8ms = 11.8ms$$

T, the period, equals 5 times the time frame at which the microcontroller wakes up from Sleep to do the detection. In the case it does the proximity detection, this time frame is about 560 ms (the double overflow period of the WDT, which is ~70 ms multiplied by the prescaler ratio, 8). If the device has detected the proximity and it performs the scanning of the whole keyboard, the time frame is only ~70 ms (WDT overflowing twice to cause a TIMER1 gate event).

Thus, in the proximity case, T will be:

EQUATION 2:

$$T = 560ms \times 5 = 2800ms$$

The DC of the VDIFF signal is Ton/T = 11.8 ms / 2800 ms = 0.00421. In a certain scenario (for instance, the Capacitive Sensing Module oscillator in low range), the VDIFF signal amplitude is, for example, 118 mV. Thus, the average value of the VDIFF signal is:

EQUATION 3:

$$VDIFF\_AVG = VDIFF\_AMPLITUDE \times VDIFF\_DC =$$
$$= 118mV \times 0.00421 = 0.049mV$$

Dividing this value by 100 Ohms, the resulted current is ~4.9 uA. This is the average current consumption by the microcontroller while it does the proximity detection.

The current value consumption while doing the detection of the entire keyboard at a higher rate is obtained by replacing period T = 5 x 560 ms with T = 5 x 70 ms. The resulted current in this example scenario is ~40 uA.

> **Note:** This current consumption calculus is based on a WDT overflow of ~35 ms. Users may base their calculations on the data sheet typical value of the WDT Time-out, but the most accurate result can be obtained only by measuring the actual value of this time out.
>
> Because the calculus resembles the approximation of a 1st order integral, meaning that one seeks for the surface beneath the VDIFF signal, the current drawn by the MCU while sleeping must be taken into consideration and added.
>
> A typical Sleep current measured on the board designed for this application is ~ 9uA. All the measurements are taken at VDD = 5V.

CONCLUSION

The Capacitive Sensing Module on the PIC16F72X implements the hardware connection between the WDT and Timer1 gate, and thus the possibility of using the WDT wake from the Sleep event as a time resource for counting pulses coming from the capacitive module to the TMR1 gate. This introduces the power-down mode (Sleep) to be used, which is essential for power saving.

The most powerful method used to bring down the current consumption of the device is to keep it as much as possible in Sleep mode. For the lowest current consumption in Sleep mode, all unused I/O pins should be tied either at V_{DD} or V_{SS}.

In non-critical applications, where the concept of enabling the user interface can be used, the proximity detection technique gets the most out of the low-power capacitive sensing concept by increasing the interval in which the MCU stays in Sleep mode.

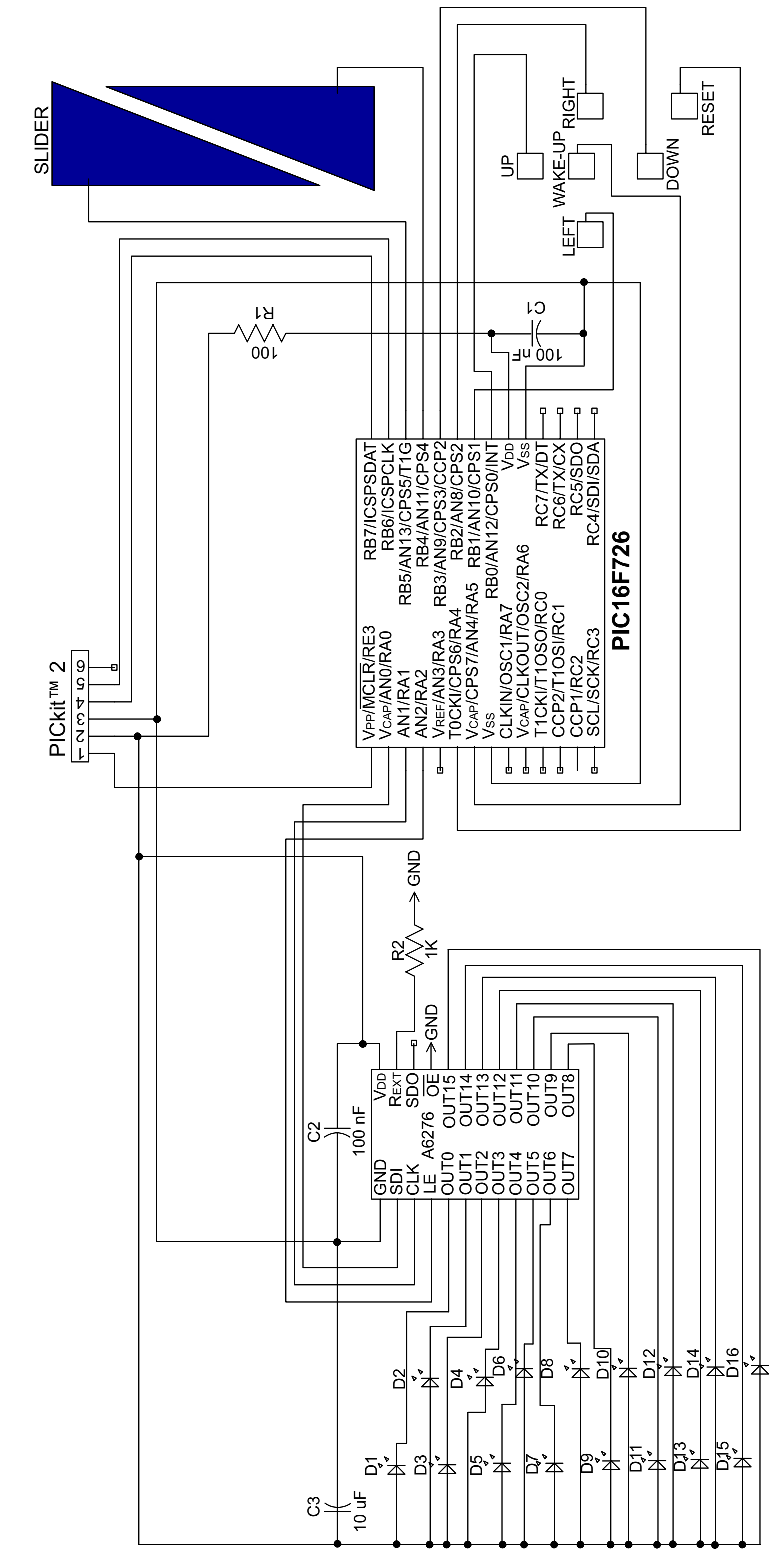
Below are some general ideas behind proximity detection; the user should:

- create a state machine-based firmware that can shift from scanning one button to scanning the whole keyboard
- increase/decrease the pulse acquisition window by choosing the WDT prescaler value according to the type of scan (proximity or normal)
- keep the scan rate at a reasonable level to maintain a fast capacitance shift detection

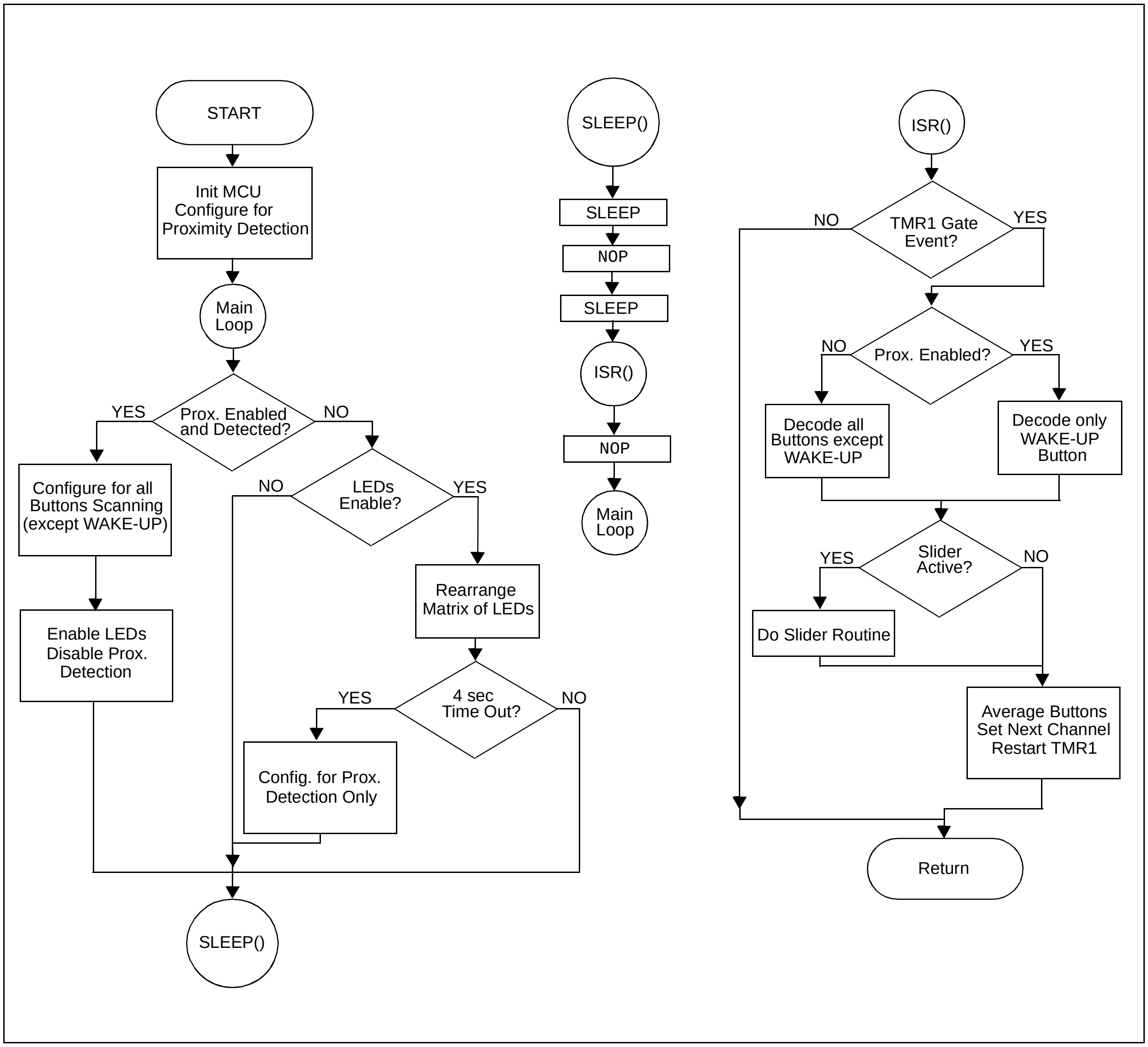
The firmware developed for the application presented here to illustrate the low-power capacitance sensing concept uses a total amount of 1,930 words of program space and 130 bytes of data memory.

The core firmware that contains the code and data on top of which users can build their application requires approximately 512 words of Flash and 80 bytes of data memory.

APPENDIX A: LOW-POWER CAPACITIVE TOUCH – PIC16F726



APPENDIX B: FIRMWARE FLOWCHART



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