INTRODUCTION

This application note shows the implementation of a software, low-power Real-Time Clock (RTC) on an 8-bit PIC16(L)F171X microcontroller using the Timer1 module. Timer1 enables the device to operate in Sleep mode, provided that it runs from an external clock source. While in Sleep mode, the device will draw minimal current. Interrupt events, such as a keypress on an Interrupt-on-Change (IOC) pin or a Timer1 overflow, can wake the device up from Sleep. At that time, the MCU can do various things, such as updating the time on the LCD, as shown in Figure 1. This implementation includes the use of the MPLAB® Code Configurator (MCC) for easier code development, and is applicable on any 8-bit PIC® microcontroller given that the required peripherals are supported.

OPERATION

Assuming that the PIC® MCU in Figure 2 is programmed correctly, the low-power RTC will operate as stated in this section. Upon power-up, the device is initialized with the time at “12:00:00 AM” and enters Sleep mode. Timer1 generates an interrupt on every second and wakes up the device from Sleep. Time variables (hours, minutes, seconds) are updated and respective characters on the LCD change (only the characters of updated variable/s change to shorten communication with the LCD). The colons flash on every second (blank for a second and displayed the next second), only to appear when the ‘seconds’ variable contains odd values. The device then returns to Sleep and waits for the next wake-up event.

The implementation of a low-power RTC operates in four modes: RUN, HR_SET, MIN_SET and FORMAT_SET. In RUN mode, only Timer1 interrupts update the LCD. Flashing colons on the LCD indicate that the RTC is in RUN mode, while static colons indicate otherwise. Both HR_SET and MIN_SET modes allow the user to set the ‘hours’ and ‘minutes’ variables. The FORMAT_SET mode gives the user an option whether to display the time in a 12-hour (by default) or 24-hour format.

Three switches are provided for setting-up the time:
- MODE_SELECT_SW (S1)
- INC_SW (S2)
- CLR_MIN_SW (S3)

Each keypress generates an interrupt for the selected modes and wakes the device from Sleep. The MODE_SELECT_SW selects the device’s mode of operation and which units are to be modified: hours, minutes, time format or none (RUN mode). The selected units flash every second. The INC_SW increments the selected units being modified. While incrementing, the selected units’ values are displayed. Upon key release, the Timer counts out one second and resumes flashing the selected units. As an additional feature, the CLR_MIN_SW clears the minutes and seconds, exactly setting the time to the “top of the hour”, as announced in radio broadcasts. Unlike the MODE_SELECT_SW, which can generate an interrupt in all modes, the other two switches can only generate interrupts selectively (INC_SW outside RUN mode and CLR_MIN_SW only in MIN_SET mode). After the INC_SW or CLR_MIN_SW keys are depressed, the user has ten seconds to depress the next key. If no keypress is detected within ten seconds, the device returns to RUN mode. The RTC program flowchart is shown in Figure 1.

This software RTC mostly relies on Timer1. The timing operation includes the Timer1 register pair (TMR1H:TMR1L), incrementing from 0x0000 or a specified value, to 0xFFFF. An overflow from 0xFFFF to 0x0000 sets the Timer1 Interrupt Flag (TMR1IF). This overflow interrupt wakes the device from Sleep and executes the Timer1 interrupt routine if enabled (TMR1IE = 1). As Timer1 continues to run upon overflow, the software must clear the flag bit and reload the Timer1 register pair with the initial values immediately. Instructions for updating the time will be executed before the device returns to Sleep.

For external interrupt sources, switches are connected to I/O pins configured as inputs with Interrupt-on-Change (IOC) enabled. A change of state from low-to-high (positive edge), or vice versa, sets an IOC interrupt flag, then wakes the device from Sleep. The program continues to the IOC interrupt routine, which clears the flag bits and contains instructions for setting the time. The device will again return to Sleep until the next wake-up event.
To display texts on the 16x2 LCD in Figure 2, the PIC microcontroller sends clock and data signals through the SCK and SDO pins of the Master Synchronous Serial Port (MSSP) module in SPI Master mode. The PIC MCU is configured as such to communicate with the I/O expander, connected between the PIC device and the LCD. Refer to the “Implementation with MPLAB® Code Configurator” section for procedures on how to set up these modules with ease.

FIGURE 1: LOW-POWER RTC PROGRAM FLOWCHART

- **Main**
  - Initialize the Device, Modules and Variables
  - The Device is Set to Begin at 12AM in RUN Mode
  - Enable Global and Peripheral Interrupts
  - Enable Interrupt on MODE_SELECT_SW
  - Display the Time on the LCD
  - Start Timer1
  - Enter SLEEP Mode

- **Interrupt Service**
  - Has Timer1 overflowed?
    - No
    - Yes
  - Is the RTC in RUN mode?
    - No
    - Yes
  - Is the RTC in RUN mode?
    - No
    - Yes
  - Enable Interrupt on INC_SW
  - Is it the INC_SW?
    - No
    - Yes
  - Clear 'tmr1Counter'
  - Is it the MODE_SELECT_SW?
    - No
    - Yes
  - Clear the Overflow Flag and Reload the Timer
  - Update the LCD Display Accordingly
  - Increment ‘tmr1Counter’ by 1 Second
  - Has ‘tmr1Counter’ reached 10 secs?
    - No
    - Yes
  - Clear ‘tmr1Counter’ and Go to RUN Mode
  - Toggel the Display of the Selected Unit

- **Main**
  - Increment the Selected Unit
  - Increment the Selected Unit
  - Clear the Minutes and Seconds Values
  - Clear the Interrupt-on-Change Flags
  - Initialize the LCD Display
DESIGN

This implementation uses the Explorer 8 Development Board, a full-featured development board and platform for 8-bit PIC® microcontrollers. Most of the components used are already provided by the board, with the exception of the Timer1 watch crystal, and a few others (additional resistors, capacitors and switch S3). Design time is minimized and code development is simplified with the use of code libraries and MCC (see “Implementation with MPLAB® Code Configurator”). For more information on the Explorer 8 board’s features and schematic, refer to the “Explorer 8 Development Board User’s Guide” (DS40001812) (http://www.microchip.com/explorer8.html).

Figure 2 shows the block diagram of the design integrated with the Explorer 8 Development Board. The RA2, RB5, RC3 and RC5 pins are the control and communication signals to the 16x2 LCD display via the MCP23S17 I/O expander. The RB<2:0> pins are the inputs for the switches. Both the system and timer clock sources use external crystal oscillators for each. The OSC1 and OSC2 pins are connected to the on-board, 8 MHz crystal oscillator as the device’s system clock source. As Timer1 needs to run in Sleep mode, it is configured to operate asynchronously to the device, connected to an external watch crystal through the SOSCI and SOSCO pins. Using a crystal oscillator is the least expensive and has the quickest start-up time. Timer1 is where an accurate frequency is required. A good choice for a crystal is a 32.786 kHz (watch) crystal.

FIGURE 2: LOW-POWER RTC SCHEMATIC DIAGRAM

The accuracy of an RTC using Timer1 depends on the accuracy of the crystal being used. The more accurate the crystal, the higher the cost. So, as always, there is a cost/performance trade-off to be made. A crystal rated with an accuracy of 20 PPM (Parts Per Million), could cause an error of about 1.7 seconds per day. For many applications, this should be adequate. But for applications where timer accuracy is critical, calibration techniques can be applied. However, additional components may be needed in monitoring the factors affecting crystal accuracy, such as aging and temperature.
LOW-POWER FEATURE

Relative to most microelectronics, LCDs are slow devices. A good portion of the time spent in the Interrupt Service Routine (ISR) is talking to and updating the LCD module. The time spent updating the display can be tracked by configuring an additional I/O pin as an indicator. Using a logic analyzer shows that the device spends approximately 5.75 ms awake. With Microchip’s eXtreme Low-Power (XLP) technology, choices of power modes can be tailored on-the-fly, allowing the circuit to consume the least possible amount of current at different times (refer to www.microchip.com/xlp for more information). To minimize power consumption, the device should be in Sleep mode as much as possible.

IMPLEMENTATION WITH MPLAB® CODE CONFIGURATOR

The MPLAB® Code Configurator (MCC) is a user-friendly plug-in tool for MPLAB® X IDE, which generates drivers for controlling and driving peripherals of PIC microcontrollers. For more information on MCC, refer to the “MPLAB® Code Configurator User’s Guide” (DS40001725) (http://www.microchip.com/code_configurator/home.html). Below are step-by-step procedures on how to set-up the system and the modules using MCC:

1. Launch MCC by going to Tools > Embedded > MPLAB Code Configurator.
2. In “Project Resources”, click on System Module and set the System Clock Source, frequency, and Configuration Bits in the Composer area.
3. Select the additional peripherals required by the application (GPIO::GPIO, TMR1::Timer and MSSP::SPI Master) under the list of peripherals in the “Device Resources” area. When selected, the peripherals will appear under “Project Resources”.
4. Individually select each peripheral from “Project Resources” and apply the necessary configurations:
   - GPIO – Select the needed I/O pins for the switches and LCD control signals by clicking on the blue locks on the “MCC Pin Manager” area. In the Composer area, assign a custom name to each pin, if desired. Configure the LCD control signals as outputs and the switches as inputs, with IOC (Interrupt-on-Change) for the MCC to generate an interrupt vector in the Interrupt Manager.
   - Timer1 – To configure Timer1 to operate with an external watch crystal, select External as the Clock Source and check the Enable Oscillator Circuit checkbox. The external frequency will be automatically set to 32.768 kHz. Set the Prescaler value to 1:1 and the Timer Period to 1000 ms. Check the Enable Timer Interrupt checkbox for the MCC to generate an interrupt vector for Timer1 in the “Interrupt Manager”.
   - SPI Master – Configure the SPI module to send serial data to the I/O expander. Check the Enable SPI checkbox to enable SPI mode. Set the Input Data Sampled at Middle; Clock Polarity to Idle: Low, Active: High; and Clock Edge as Active to Idle. Under SPI Clock, choose the Clock Source required by the I/O expander. Allocate the SPI data and clock pins to the device by clicking on the SDO and SCK pins on the “Pin Manager” area.
5. In the “Interrupt Manager”, check the Preemptive Interrupt Routine checkbox and arrange the Interrupt Sources with Timer1 as the first priority.
6. Click the Generate Code button on the top left corner of the “Composer area” for the MCC to generate individual source and header files for each module. The MCC also generates a main.c source file for the user’s convenience, wherein the initialization codes are called and an empty while (1) loop is provided for custom code entry.
To add custom codes in the interrupt routines, open the Action Items tab from Window > Action Items and double-click on the Interrupt Source. Aside from the MCC generated files, additional source codes and headers are included to support the application. Figure 3 shows the MCC setup for the low-power RTC.

FIGURE 3: MPLAB® CODE CONFIGURATOR SET-UP
ALTERNATIVE IMPLEMENTATIONS

The program written for this application note shows one method for an RTC. Trade-offs between code size, current consumption and desired operation have been made. Some possible alternative implementations are:

1. Turn off the display during Sleep.
2. Use dynamic power-saving modes to support additional processes.
3. Instead of Timer1, use a Real-Time Clock and Calendar (RTCC) module.

Depending on the requirements of the application and the characteristics of the display, Alternative 1 could be implemented by turning the power off and on (at a given rate) to the display. This technique may lead to a lower system current consumption. Evaluation of the desired display/display driver is recommended.

For applications having additional tasks and processes alongside the RTC, implementation may require more peripherals and CPU operation. These tasks may limit the device’s use of Sleep mode. Alternative 2 suggests using dynamic power-saving modes that can still effectively reduce power consumption without putting the device to Sleep. More information on these modes are provided in the technical brief TB3144, “Doze, Idle and PMD Features of 8-Bit PIC® Microcontrollers” (www.microchip.com).

Alternative 3 introduces the Real-Time Clock and Calendar (RTCC), which offers not only accurate time and date-keeping, but also the capability for user calibration and low-power usage (among many others). RTCC can be implemented either as an external component or as an internal module in PIC® microcontrollers. However, only a few 8-bit PIC microcontrollers have this module. A complete list of devices and features can be found on www.microchip.com/rtcc. For a more detailed discussion about the peripheral, refer to TB3124, “Real-Time Clock and Calendar Technical Brief” (www.microchip.com).

CONCLUSION

The Timer1 module allows many applications to include a Real-Time Clock at a minimal system cost. eXtreme Low-Power (XLP) technology features make the design more efficient in terms of power consumption. Implementation is also more convenient with the use of the MPLAB Code Configurator (MCC).

This time function can be useful in consumer applications (display time), as well as in industrial applications (data timestamp). The accuracy of the time is strictly dependent on the accuracy of the crystal.
APPENDIX A: SOURCE CODE LISTING

The latest software version can be downloaded from the Microchip web site (www.microchip.com). The user will find the source code appended to the electronic version of this application note.
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